Telecommunications
Satellite Communications

Principles of Satellite Communications

Courseware Sample

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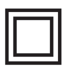
Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* sign ⚠, indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
⎓	Direct current
∿	Alternating current
	Both direct and alternating current
3∿	Three-phase alternating current
⏚	Earth (ground) terminal

Safety and Common Symbols

Symbol	Description
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

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Preface

Since the Soviet Union shocked the western world by launching the first artificial satellite, SPUTNIK I, on October 4, 1957, the science of satellites and satellite communications has undergone an amazing evolution. Today satellites play an essential role in global communications including telephony, data networking, video transporting and distribution, as well as television and radio broadcasting directly to the consumer. They fulfill critical missions for governments, the military and other organizations that require reliable communications links throughout the world, and generate billions of dollars annually in revenue for private enterprise.

Communications satellites offer several important advantages over other types of long-range communications systems: the capability of direct communication between two points on earth with only one intermediate relay (the satellite), the ability to broadcast or collect signals and data to or from any area ranging up to the entire surface of the world, and the ability to provide services to remote regions where ground-based, point-to-point communications would be impractical or impossible.

One of the greatest advantages of satellite communications systems is the ratio of capacity versus cost. Although satellites are expensive to develop, launch and maintain, their tremendous capacity makes them very attractive for many applications. INTELSAT I, launched in 1965, had a capacity of only 240 two-way telephone channels or one two-way television channel, and an annual cost of \$32 500 per channel. Since then, the capacity and lifetime of communication satellites have increased tremendously resulting in a drastic reduction in the cost per channel. Communications satellites now have capacities sufficient for several hundred video channels or tens of thousands of voice or data links.

In addition to applications designed specifically for communications purposes, satellites are used extensively for navigation systems, scientific research, mapping, remote sensing, military reconnaissance, disaster detection and relief and for many other applications. All of these applications, however, require at least one communications link between the satellite and one or more earth stations.

The Satellite Communications Training System is a state-of-the-art training system for the field of satellite communications. Specifically designed for hands-on training, the system covers modern satellite communication technologies including analog and digital modulation. It is designed to use realistic satellite uplink and downlink frequencies at safe power levels and to reflect the standards commonly used in modern satellite communications systems.

The Orbit Simulator provides interactive visualization of satellite orbital mechanics and coverage, and the theory behind antenna alignment with geostationary satellites. The optional Dish Antenna and Accessories provides hands-on experience in aligning a typical antenna with real geostationary satellites.

Preface

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

About This Manual

Manual Objective

When you have completed this manual, you will be familiar with the principles of satellite communications. You will be familiar with the different segments of a satellite communications system and the main components and characteristics of each segment.

You will be familiar with the main baseband processing and modulation/demodulation techniques used in both analog and digital satellite communications. You will also be familiar with the basic troubleshooting techniques applicable to satellite communication systems including remote troubleshooting of the satellite repeater using telemetry.

Description

Each exercise contains:

- A clearly defined Exercise Objective
- A Discussion Outline listing the main points presented in the Discussion
- A Discussion of the theory involved
- A Procedure Outline listing the main sections in the Procedure
- A step-by-step Procedure in which the student observes and measures the important phenomena, including questions to help in understanding the important principles.
- A Conclusion
- Review Questions

In this manual, all New Terms are defined in the Glossary of New Terms. In addition, an index of New Terms is provided at the end of this manual.

Systems of units

Units are expressed using the SI system of units.

Safety considerations

Safety symbols that may be used in this manual and on the equipment are listed in the Safety Symbols table at the beginning of the manual.

Safety procedures related to the tasks that you will be asked to perform are indicated in each exercise.

Make sure that you are wearing appropriate protective equipment when performing the tasks. You should never perform a task if you have any reason to think that a manipulation could be dangerous for you or your teammates.

When studying communications systems, it is very important to develop good safety habits. Although microwaves are invisible, they can be dangerous at high

levels or for long exposure times. The most important safety rule when working with microwave equipment is to avoid exposure to dangerous radiation levels.

The radiation levels in the Satellite Communications Training System are too low to be dangerous. The highest power level in the system is at the RF OUTPUT of the Earth Station Transmitter and is typically 5 dBm (approximately 3.2 mW) at 11 GHz. The maximum power density that can be produced by the Satellite Communications Training System using the supplied equipment is approximately 0.13 mW/cm^2, well below all Canadian, American and European standards for both microwave exposed workers and the general public.

For more detailed information, refer to the section *Safety with RF fields* of this manual.

To the Instructor

You will find in this Instructor Guide all the elements included in the Student Manual together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to you is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to another. For this reason, the results and answers given in this manual should be considered as a guide. Students who correctly performed the exercises should expect to demonstrate the principles involved and make observations and measurements similar to those given as answers.

List of Equipment Required

Satellite Communications Training System

The following equipment and software is included in the Satellite Communications Training System and is required to perform the procedures in this manual:

Qty	Description	Model
1	Earth Station Transmitter	9570
1	Earth Station Receiver	9571
1	Satellite Repeater	9572
1	Accessories	9579
1	Orbit Simulator and Software Suite[1]	9581

The Orbit Simulator and Software Suite consists of three applications:

- *Orbit Simulator*
- *Telemetry and Instrumentation*
- *Data Transfer*

[1] The Data Transfer application is used in this manual. If you have the optional Telemetry and Instrumentation Add-On, the Telemetry and Instrumentation application is also used.

Optional equipment

Qty	Description	Model
1	Telemetry and Instrumentation Add-On	8093-1

This Add-On consists of two modules, the Data Generation/Acquisition Interface, Model 9573, and the Virtual Instrument Package, Model 1250-A0. These modules, along with the Telemetry and Instrumentation application, provide a telemetry interface with the Satellite Repeater as well as a full suite of virtual instruments.

Telemetry with the Satellite Receiver is only possible using the Telemetry and Instrumentation Add-On.

If the Telemetry and Instrumentation Add-On is not purchased, conventional instruments must be supplied by the user (see Conventional instruments *below).*

If you have the Telemetry and Instrumentation Add-On, a conventional dc voltmeter (or multimeter) would also be useful, but is not essential, for part of Exercise 3-3.

List of Equipment Required

Conventional instruments

The following conventional instruments can be used instead of the Telemetry and Instrumentation Add-On:

Qty	Description	Minimal specifications and notes	
1	Oscilloscope	Frequency range:	0 – 100 MHz
1	Spectrum Analyzer	Frequency range:	near 0 – 11.26 GHz
1	Waveform Generator (function generator)	Functions:	Sine White noise (optional)
		Output Level:	0 – 1 V
1 to 3	Binary Sequence Generators (data generators)	Bit rate:	10 kbit/s – 20 Mbit/s
		Modes:	PRBS (variable length) User entry (1 to 32 bits)
		Clock:	External input
		Outputs:	Data Sync. (one pulse per sequence)
1	DC Voltmeter (or multimeter)	For measuring the dc voltage at the POWER SENSOR OUTPUTs.	

Computer requirements

The software requires a current model computer running Windows® 7, Windows® Vista or Windows® XP.

The Satellite Communications Host Computer, Model 9695-B0, meets or exceeds these requirements.

List of Equipment Required

System configurations and capabilities

The following table gives different system configurations and shows the capabilities of each configuration:

This product:	Plus these items:	Provide these Satellite Communications Capabilities:		
		Analog/digital satellite link, signal display and measurement, troubleshooting the transmitter and receiver	Data transfer	Telemetry, troubleshooting the repeater, virtual instrumentation
Satellite Communications Training System	• Telemetry and Instrumentation Add-On • Computer	✓	✓	✓
	• User-supplied conventional instruments • Computer	✓	✓	
	• User-supplied conventional instruments (no computer)	✓		

When performing data transfer using one computer, the data sent from the computer is transmitted over the satellite link and received by the same computer. The Data Transfer software allows using two computers, a sending computer connected to the Earth Station Transmitter and a receiving computer connected to the Earth Station Receiver.

Sample Exercise

Extracted from

the Student Manual

and the Instructor Guide

Exercise 1-1

Satellite Communication Systems

EXERCISE OBJECTIVE

When you have completed this exercise, you will be familiar with the basic concepts of satellite communications systems, including the different segments of a satellite communications system, the main types of services provided and the frequency bands used. In addition, you will be familiar with the Satellite Communications Training System.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Segmentation of a satellite communications system
- Satellite communications services and frequency bands
- Quality of Service (QoS)
- The Satellite Communications Training System
- The Telemetry and Instrumentation Add-On
- Signal levels
- Safety with RF fields

DISCUSSION

Segmentation of a satellite communications system

A satellite communications system is a complex system that consists of many different elements. The system requires the constant attention of many skilled people in order to remain operational.

A typical system can be divided into three distinct segments (see Figure 1-11).

- The **ground segment (GS)** consists of the earth stations and other ground-based facilities used for communications traffic. With some systems, such as with the global positioning system (GPS), broadcasting satellite service (BSS) systems — also called direct broadcasting service (DBS), very small aperture terminal (VSAT) networks, and some military satellites, earth stations consist entirely of user terminals that interface directly with the space segment. In this case, the ground segment may be called the **user segment (US)**.
- The **space segment (SS)** consists of one or more satellites in space, including both active and spare satellites. A group of active satellites is said to form a **constellation**. The launch vehicle and all of the facilities required to launch satellites and place them in orbit are also considered part of the space segment.
- The **control segment (CS)** includes all of the ground equipment and facilities that are required for operation, control, monitoring and management of the space segment and, in many systems, management of the terrestrial network.

Information is transmitted over free-space links. A one-way link from the ground to the satellite is called an **uplink**. A link from the satellite to the ground is a **downlink**.

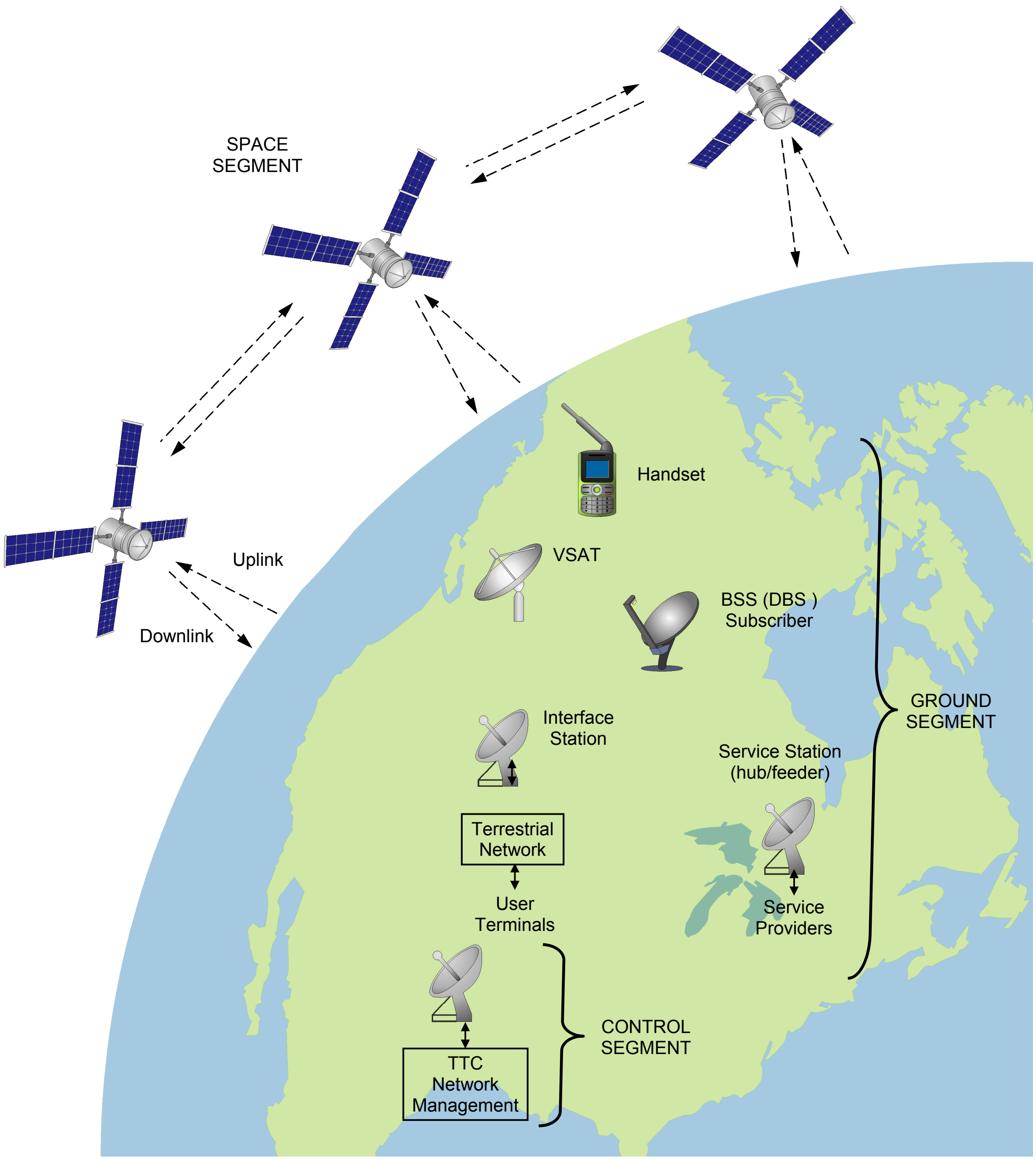

Figure 1-11. Satellite communications system segments.

Ground segment

The ground segment consists of all of the traffic earth stations in the system. These earth stations may be of several types, and the 'size' of the stations (that is, the diameter of the antenna) may range from very small (a few centimeters) to

very large (tens of meters), depending on the application and the types of services offered by the system.

There are three basic types of earth stations, as shown in Figure 1-11. A satellite communications system may include a combination of these types:

- **User stations** are user terminals that interface directly with the space segment. These include **very small aperture terminals (VSATs)** with antenna sizes ranging below 3 m, **ultra small aperture terminals (USATs)** with antenna sizes under 0.5 m, mobile units and handsets as well as receiving terminals for Broadcasting Satellite Service (BSS), also known as Direct Broadcast Service (DBS) or Direct-to-Home (DTH).
- **Interface stations** act as gateways between the space segment and a terrestrial network to which user terminals are attached. Today, these interface stations are typically from 2 to 10 m in size. Early INTELSAT earth stations in the mid ‘60s measured up to 30 m.
- **Service stations** act as an interface between the space segment and a terrestrial service provider. A connection between a service provider and the users usually goes through a feeder station (for broadcasting services, etc.) or a hub (for collecting services).

A one-way connection from a user terminal through all associated ground facilities, the ground segment, and the space segment, back to the ground segment and to another user terminal, is called a **simplex connection**. Two-way communication requires a **duplex connection** consisting of two simplex connections, one for each direction.

In any communications system, the *signal* is the voltage or waveform that conveys information from one user terminal to another. The adjective **baseband** is used to describe signals whose range of frequencies is measured from approximately 0 Hz to the highest frequency in the signal. The **baseband signal** is therefore the signal that initially represents the information one wants to convey. The baseband signal can either be *analog* (taking on any value within a given range) or *digital* (taking on a finite number of discrete values).

At the transmitting earth station, the baseband signal is used to modulate a sinusoidal carrier. The modulation technique used depends on the type of baseband signal being transmitted. To transmit an analog baseband signal, analog modulation, usually FM, is used. To transmit a digital baseband signal, digital modulation, usually a form of phase-shift keying (PSK), is used.

The modulation process shifts the baseband signal up in frequency so that it is centered on the frequency of the carrier and filters it so that it occupies only the necessary frequency range. This range is called the **intermediate frequency (IF)**. This signal is usually shifted to a higher frequency (**up conversion**) one or more times to the **radio frequency (RF)**. With satellite communications, the RF band for a particular earth station is typically somewhere between 1 and 30 GHz. Using high frequencies reduces atmospheric attenuation and allows constructing high gain antennas of reasonable size.

The earth station antenna transmits the RF signal to the satellite repeater. The repeater retransmits the signal to one or several earth stations. At the receiving earth station, the received RF signal is shifted to a lower frequency (**down conversion**) in one or more stages to an IF frequency. The IF signal is then demodulated in order to recover the original baseband signal.

The overall downlink bandwidth of a satellite repeater is usually split into several sub-bands by a set of filters and each sub-band is amplified separately. One sub-band is referred to as a **satellite channel** and the equipment related to this sub-band is called a **transponder**, a combination of the words *transmitter* and *responder*.

Information is transmitted over the uplink and downlink using modulated carriers. In many cases, each carrier can carry several signals simultaneously by the use of time division multiplexing (TDM) or frequency division multiplexing (FDM). Each carrier, therefore, can be considered to provide a number of *channels*. The signals are multiplexed in the baseband into a single signal that modulates a carrier which is transmitted to the satellite and relayed to another earth station. This is referred to as **multiple channels per carrier (MCPC)** (sometimes called *multiple connections per carrier*). The modulated carrier usually occupies the entire bandwidth of one transponder.

MCPC using FDM can be used to transmit multiplexed analog voice signals. MCPC using TDM is used to transmit multiplexed digital signals, such as digital television channels for direct broadcasting to subscribers.

When there is no baseband multiplexing, each carrier provides only one channel. This arrangement is called **single channel per carrier (SCPC)** (sometimes called *single connection per carrier*). It is much simpler than MCPC and is frequently used to transmit analog television signals. It is typically used for feeds rather than for direct programming. With SCPC, a channel often provides a dedicated, permanent connection between two earth stations.

Table 1-1 shows some of the advantages and disadvantages of SCPC and MCPC.

Table 1-1. Comparison of SCPC and MCPC.

	SCPC	MCPC
Advantages	• Uses simple and reliable technology and low-cost earth station equipment. • One connection can use any bandwidth up to the full bandwidth of a transponder. • Easy to uplink from multiple transmitting earth stations to the same transponder. • Easy to add additional receiving earth stations.	• More efficient use of available bandwidth. Many multiplexed signals can be transmitted using one carrier that occupies the full bandwidth of a transponder. No guard bands are required. • Does not require a dedicated channel for each connection. • Ideal for burst transmissions such as packet data transmission.
Disadvantages	• Less efficient use of bandwidth. Guard bands must be used when a transponder is shared by multiple carriers in order to prevent mutual interference. • Inefficient for burst transmission. • Customer pays for a dedicated connection even when it is not being used, unless SCPC DAMA is implemented.	• All signals are multiplexed at one location and demultiplexed at another location. This requires a network infrastructure.

With single channel per carrier (SCPC), the bandwidth of a modulated carrier may be less than the bandwidth of one transponder. In this case, other modulated carriers of somewhat different frequencies can pass through the same transponder, providing a guard band is left between each of the modulated signals so that their frequency ranges do not overlap. Using different carrier frequencies to give several signals simultaneous access to the same transponder is called **frequency division multiple access**.

When a dedicated connection is not required, an SCPC connection can be established temporarily for communications between two earth stations and then terminated at the end of the communication. This arrangement, called **SCPC demand assigned multiple access (SCPC DAMA)**, allows the carrier to be used by different parties one at a time.

Another type of multiple access is called **time division multiple access (TDMA)**. At each earth station, a TDMA terminal divides access to the satellite into regular time slots. During each time slot, a burst of data from a particular source is transmitted from one earth station to one of the satellite transponders. The transponder retransmits the burst to another earth station where a TDMA terminal routes the data to the correct destination. A buffer memory at each TDMA terminal allows continuous data transfer with the terrestrial network.

Space segment

There are many different types of satellites providing a wide variety of capabilities and services. All satellites, however, have two main subsystems: the payload and the platform. The **payload** consists of all the equipment on the satellites that carries out the mission of the satellite. On a communication satellite, the payload consists of all the components that provide communications services, that is, which receive, process, amplify and retransmit information. The payload can be divided into two parts: the *antennas* and the *repeater*.

An **antenna** is a conductive structure designed to receive and transmit electromagnetic energy. The satellite antennas serve as interfaces between the uplink and downlink signals and the components inside the satellite. Antennas may be designed for different types of **coverage**, a term that designates the area on the earth where communication with the satellite is possible. With *global coverage*, communication is possible with roughly all points on earth that are visible from the satellite. With *reduced coverage* (zone coverage or spot coverage), the coverage is concentrated on a particular region of the visible earth in order to make efficient use of the available power (see Figure 1-12).

The elevation is the angle that an antenna must be raised above the horizon in order to point directly at the satellite.

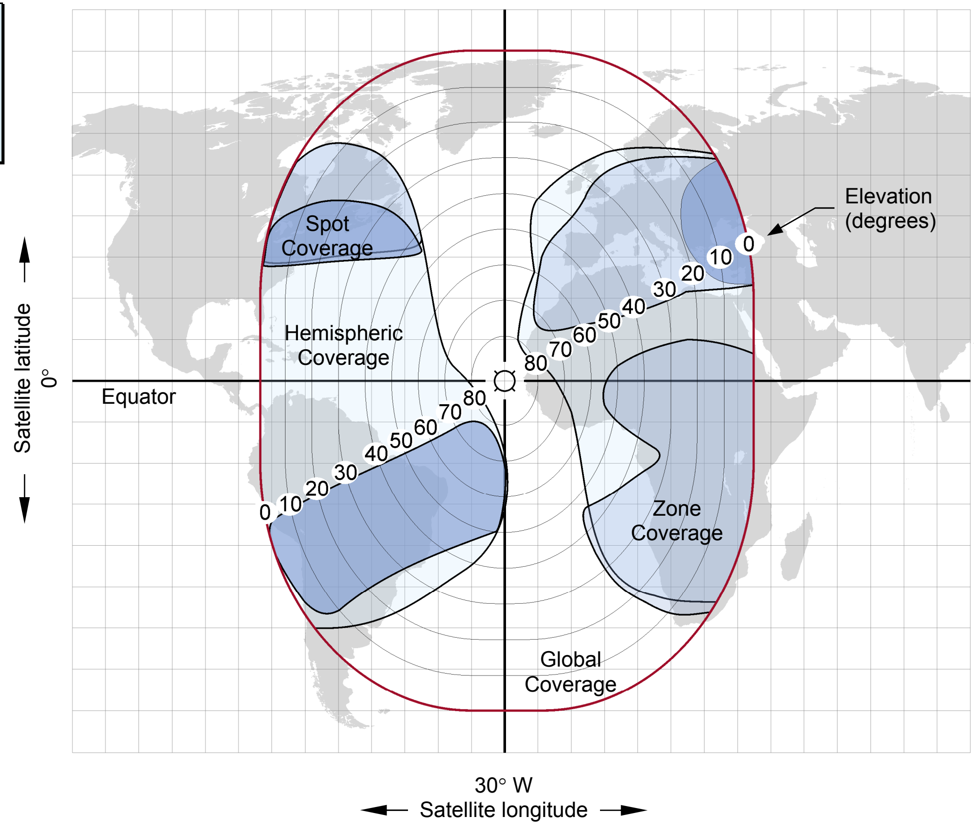

Figure 1-12. Global, zone, and spot coverage of a geostationary satellite.

Spot coverage antennas may have fixed or steerable beams. Where the coverage must be contoured to cover an arbitrary region, such as a continent, multiple beam antennas can be used.

The term *repeater* originated with telegraphy and referred to an electromechanical device used to regenerate telegraph signals. Use of the term has continued in telephony, data communications and satellite communications.

Besides the antennas, the remaining components of the payload make up the **repeater**. There are two main types of repeater for a communications satellite: transparent and regenerative. A **transparent repeater** (or transparent payload) does not demodulate the uplink signal. Instead, it simply shifts the uplink signal to a different frequency (usually a lower frequency) and amplifies it for retransmission over the downlink.

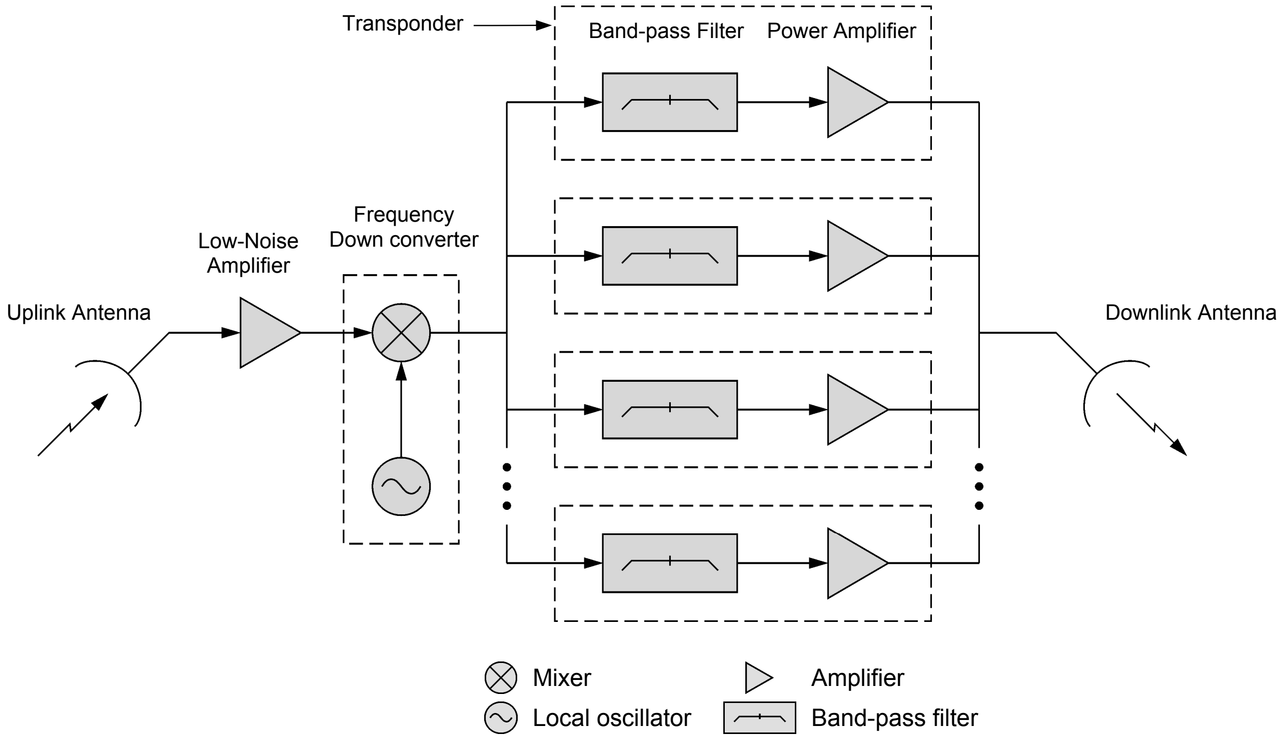

Figure 1-13. Transparent payload or repeater.

Figure 1-13 shows a simplified block diagram of a transparent repeater. The uplink signal from the antenna is amplified and then down-converted to the downlink frequency range in order to prevent the strong downlink signal from interfering with the weak uplink signal. The overall downlink bandwidth of a satellite repeater is usually split into several sub-bands by a set of filters and each sub-band is amplified separately. One sub-band is referred to as a **satellite channel** and the equipment related to this sub-band is called a **transponder**, a combination of the words *transmitter* and *responder*. Each transponder usually has sufficient bandwidth for a number of carriers at different frequencies or for one wideband multiplexed signal. (See Appendix F *Satellite Transponders* for an example of the frequencies, polarizations and channels of a typical satellite.)

Filters and other components are used to reject out-of-band noise and interference and to improve performance. The power gain of each transponder is of the order of 100 to 130 dB and typically raises the power of the uplink signal from a few hundred picowatts to the downlink power of roughly ten to one hundred watts. When multi-beam antennas are used, the routing of signals from one up beam to a given down beam is done at the RF frequency.

A **regenerative repeater** (or regenerative payload) demodulates the uplink signal to recover the baseband signals, carries out baseband signal processing and switching, and then remodulates the baseband signals with a carrier at the downlink frequency (different from the uplink frequency) before power amplification and retransmission (see Figure 1-14). Although this is more complex and costly than a transparent payload, it allows onboard processing and signal routing at the baseband.

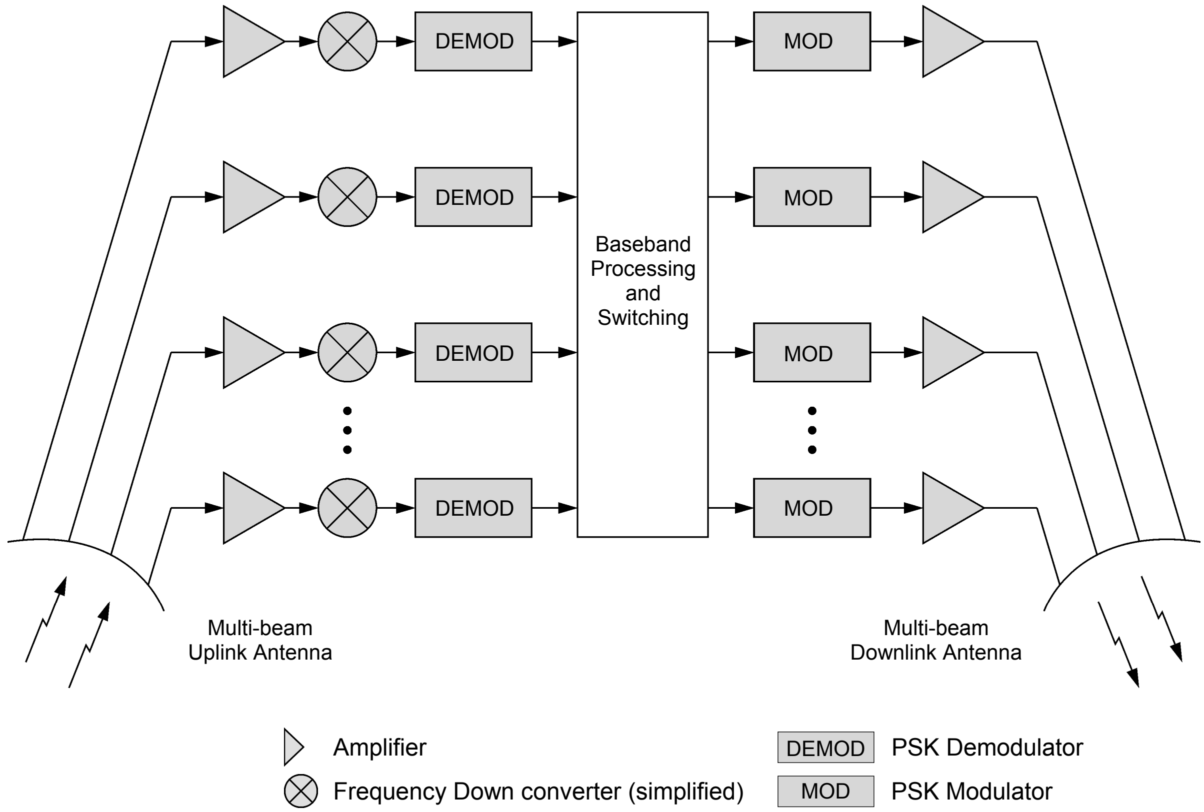

Figure 1-14. Regenerative payload.

Analog satellite communication systems are exclusively the regenerative type. Digital systems may use either type.

The attitude of a satellite is its orientation with respect to a given frame of reference. Attitude control can be done by making the satellite spin or by using an internal gyroscope and thrusters to stabilize it in three axes.

The **platform**, often called the bus, consists of all the components that permit the payload to operate and remain operational over a long period of time. The platform provides the mechanical structure of the satellite, supplies electrical power to the payload, and has propulsion and control systems used to maintain the satellite in the desired orbit and attitude as well as a system to maintain thermal stability. The platform also has provision for two-way communication with the control segment.

The most common type of electrical power system in a satellite consists of a combination of solar cells and rechargeable batteries. Solar irradiance varies over time due to variations in sun spot activity and other factors. On the average, its value is roughly 1370 W/m^2 (130 W per square foot). Since solar cells have only limited efficiency (approximately 15% for conventional silicon solar cells), satellites requiring high power must have a large area of solar cells. Batteries are required because the satellite spends some time in a state of eclipse, that is, in the earth's or the moon's shadow. For a geostationary satellite, eclipses occur during two 45 day periods per year and can have a duration as long as 72 minutes. Low earth orbit satellites can spend up to 50% of their time in eclipses of shorter duration (30 to 40 minutes).

Control segment

The control segment consists of ground facilities used for platform and payload monitoring and control as well as management of communications traffic and of the various communications resources of the satellites. Platform and payload monitoring and control are accomplished using **tracking, telemetry and command (TTC or TT&C)** (sometimes called *tracking, telemetry and control*). It may also be referred to as *tracking, telemetry, command and monitoring (TTC&M)*.

The TTC system performs the following functions:

Tracking: Detecting the precise location of the satellite.

Telemetry: Monitoring the status of the various components of the payload and of the platform, acquiring confirmation of commands, and transmitting this information to the control segment on the ground.

Command: Receiving signals from the control segment on the ground in order to control onboard equipment and to initiate maneuvers.

Satellite communications services and frequency bands

Types of satellite services

Although the radio frequency portion of the electromagnetic spectrum covers a vast range of frequencies, only a portion of this range is suitable for satellite communications. Below approximately 100 MHz, the ionosphere causes a high degree of attenuation. In addition, the spectrum between 300 MHz and 1 GHz is exceedingly crowded with terrestrial applications, which could result in interference between different applications.

The choice of the frequency band for satellite communications involves a trade-off between several constraints. In general, the lower the frequency band, the better the propagation characteristics, but the higher the frequency band, the greater the available bandwidth. For some applications, such as Mobile Satellite Services (MSS), the propagation characteristics are crucial and the bandwidth required by each service is relatively small, so lower frequency bands are generally used. Other applications, such as direct-to-home (DTH) broadcasting and broadband data services, are only practical in higher frequency bands because of the large bandwidth required. With these higher frequency bands, antennas are more directional. Directional antennas offer the added benefit of using spatial separation to avoid interference between links using the same frequency.

Frequency bands are referred to using adjectives or letter designations. Table 1-2 shows adjectival designations for frequency bands used in satellite communications.

Table 1-2. Frequency band adjectival designations.

Band	Full Name	Frequency Range	Unit
VHF	Very High Frequency	30 – 300	MHz
UHF	Ultra High Frequency	0.3 – 3	GHz
SHF	Super High Frequency	3 – 30	GHz
EHS	Extremely High Frequency	30 – 300	GHz

Letter designations for frequency bands originated during early microwave research and are still frequency used for frequencies over 1 GHz. Table 1-3 provides a summary of the frequency bands commonly used in satellite communications.

Table 1-3. Frequency bands used in satellite communications.

Band	Frequency Range	Unit
VHF	30 – 300	MHz
UHF	300 – 1000	MHz
L	1 – 2	GHz
S	2 – 4	GHz
C	4 – 8	GHz
X	8 – 12 8 – 12.5*	GHz
Ku	12 – 18 12.5 – 18*	GHz
K	18 – 27 18 – 26.5*	GHz
Ka	27 – 40 26.5 – 40*	GHz
Q	40 – 60	GHz
V	60 – 75	GHz
W	75 – 110	GHz

* in North America

The frequency ranges shown in Table 1-3 and Table 1-4 should be considered as being approximate. Some references give slightly different limits for certain bands.

The usage of radio frequencies for different services is regulated by the International Telecommunication Union (ITU), a United Nations organization. The ITU publishes Radio Regulations (RR) which refer to the following types of satellite services:

- **Fixed Satellite Service (FSS)**: A satellite service that uses fixed terrestrial terminals. In other words, FSS is any satellite service where the ground station does not change locations frequently. Examples are:
  - Point-to-point communications
  - Corporate networks
  - Very small aperture terminal (VSAT) terminals
  - Transportable terminals that remain fixed during use, such as satellite newsgathering (SNG) terminals
- **Mobile Satellite Service (MSS)**: A satellite service that uses portable terrestrial terminals, mainly for telephone communications. MSS terminals may be mounted on a ship, an airplane, or a vehicle, or, as with portable satellite telephones, may even be carried by a person. The major supplier of MSS services is INMARSAT. MSS services are divided into three main categories:
  - Maritime Mobile Satellite Service (MMSS)
  - Aeronautical Mobile Satellite Service (AMSS)
  - Land Mobile Satellite Service (LMSS)
- **Broadcasting Satellite Service (BSS)**: A type of Fixed Satellite Service used to provide audio and video entertainment directly to consumers. The terms Direct Broadcast Satellite or Direct Broadcast Service (DBS), or Direct-to-Home (DTH) are also used.
  - BSS-TV is designed to provide conventional television signals directly to the consumer.
  - BSS-HDTV is designed to provide high-definition television signals directly to the consumer.
  - BSS-Sound is designed to provide high quality audio signals to fixed and mobile consumer terminals. The term satellite digital audio radio service (SDARS) is also used.
- Other services:
  - Space Operation Service (SOS): A radio communication service concerned exclusively with the operation of spacecraft, in particular tracking, telemetry and command.
  - Amateur Satellite Service (ASS) or Amsat
  - Earth Exploration Satellite Service (ESSS)
  - Radio Determination Satellite Service (RSSS)
  - Radio Navigation Satellite Service (RNSS)
  - Space Research Service (SRS)
  - Intersatellite Service (ISS)

The Radio Regulations specify detailed radio spectrum allotments for the different services. These regulations are voluminous and very detailed. Table 1-4 provides a brief summary. Frequency bands are identified in this table using letter or adjectival designations. Some bands are also referred to using approximate uplink and downlink frequencies. For example, the "6/4 band" is another name for the C-band. The names "13/11 band", "13-14/11-12 band" and "18/12 band" all refer to different segments of the Ku band.

Table 1-4. Satellite frequency allotments (ITU Radio Regulations).

Service	Use	Band (Letter)	Band (GHz up/down)	Typical Frequencies (GHz)	
				Uplink	Downlink
Fixed Satellite Service (FSS)	Older systems (e.g. INTELSAT)	C	6/4	5.85 – 7.075	3.4 – 4.2
	Government	X	8/7	7.90 – 8.40	7.25 – 7.75
	Current operational developments (e.g. UTELSAT)	Ku	13/11 14/12	13.75 – 14.8	10.7 – 11.7
	Offers large bandwidth and little interference due to current limited use	Ka	30/20	28.0 – 30.0	17.7 – 19.7
	Developing technologies	V	50/40	50	40
Mobile Satellite Service (MSS)	Non-geostationary systems	VHF UHF		0.148 – 0.150 0.454 – 0.460	0.137 – 0.138 0.400 – 0.401
	Mostly geostationary systems (e.g. INMARSAT)	L		1.626 – 1.66	1.525 – 1.56
	Non-geostationary satellite phone systems (e.g. GLOBALSTAR)	L/S		1.61 – 1.625 (L)	2.483 – 2.5 (S)
	International Mobile Telecommunications-2000 (IMT-2000)	S		1.98 – 2.01	2.17 – 2.20
	Non-geostationary systems	S		2.65 – 2.69	2.5 – 2.54
Broadcasting Satellite Service (BSS)		S		2.67 – 2.69	2.5 – 2.52
		Ku	18/12	17.7 – 18.2	11.2 – 12.2
		Ka	25/22	24.75 – 25.25	21.4 – 22.0
Space Operations Service (SOS)	Telemetry, tracking and command (TTC)	S		2.025 – 2.120	2.2 – 2.3

Most satellite communications systems operate in the C, X, Ku or Ka bands of the microwave spectrum. These frequencies allow large bandwidth while avoiding the crowded UHF frequencies and staying below the atmospheric absorption of EHF frequencies. Satellite TV either operates in the C band for the

traditional large dish fixed satellite service or Ku band for direct-broadcast satellite. Military communications run primarily over X or Ku-band links, with Ka band being increasingly used for VSAT communications and for Milstar (the Military Strategic and Tactical Relay) system of the United States Air Force.

Quality of Service (QoS)

Ideally, the recovered baseband signal would be a perfect copy of the original baseband signal and with no delay. In addition, communication would be perfectly reliable with no interruption. In a practical communications system, however, these ideals are never met. The recovered baseband signal contains noise (analog signal) or bit errors (digital signal). There is a non-negligible delay between the recovered signal and the original. Also, there may be periods when transmission is not possible, that is, when the communications channel is not available. The term **quality of service (QoS)** refers to quantitative measurements of the performance, delay and availability provided by the system. Required QoS levels are often specified in a **service level agreement (SLA)**, a contract between a service provider and its customer that defines the minimum QoS needed for customer application performance.

For an analog baseband signal, performance is measured in terms of the *signal to noise ratio (S/N)*. For a digital baseband signal, it is measured in terms of *bit error ratio* or *bit error rate (BER)*. Delay is measured in milliseconds, and availability is the fraction of time during which the communications service is provided with the desired performance.

Factors that affect the quality of service in a satellite communications system are covered in detail in the manual *Link Characteristics and Performance*.

The Satellite Communications Training System

The Satellite Communications Training System is a state-of-the-art training system for the field of satellite communications. Specifically designed for hands-on training, the system covers modern satellite communication technologies including analog and digital modulation. It is designed to use realistic satellite uplink and downlink frequencies at safe power levels and to reflect the standards commonly used in modern satellite communications systems.

The Satellite Communications Training System includes three RF modules: the Earth Station Transmitter, the Earth Station Receiver, and the Satellite Repeater.

The Earth Station Transmitter and the Earth Station Receiver are designed to teach both wideband analog and high-speed digital baseband processing and modulation/demodulation techniques as well as frequency conversion between the intermediate and RF frequencies. The Satellite Repeater is designed to teach the operation of a transparent repeater.

Two other modules, the Data Generation/Acquisition Interface and the Virtual Instrument, are part of the optional Telemetry and Instrumentation Add-On.

The Earth Station Transmitter

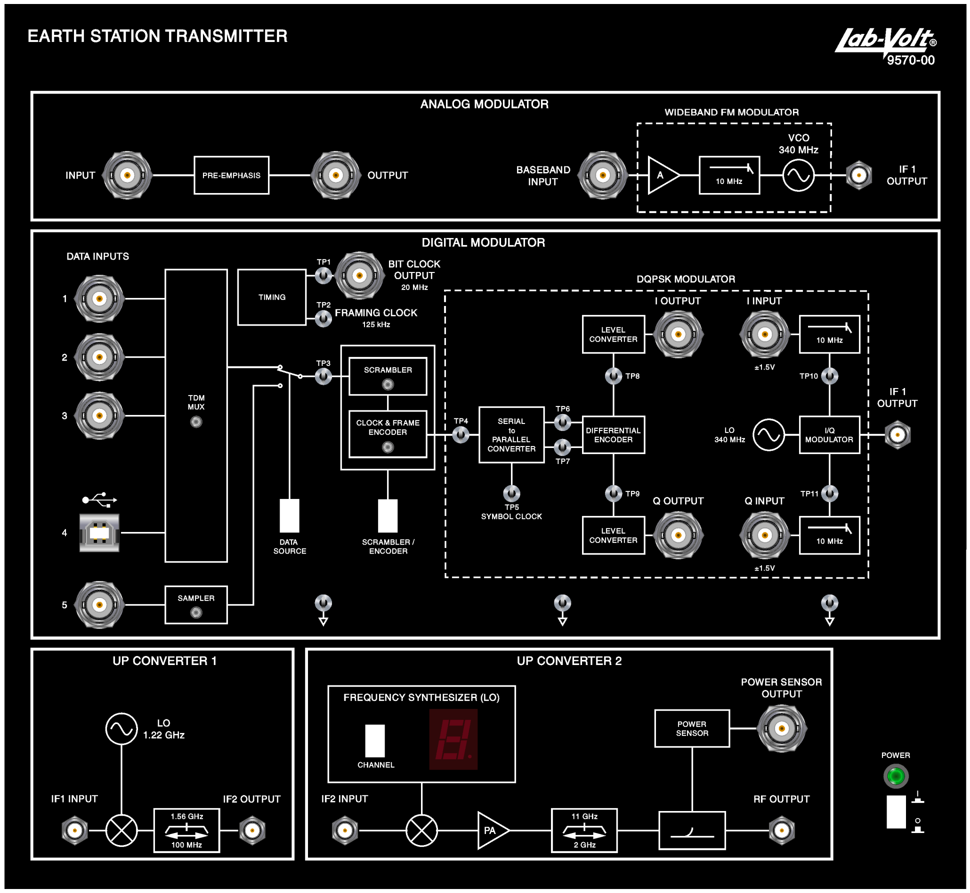

Figure 1-15. The Earth Station Transmitter.

The Earth Station Transmitter, Model 9570, includes an Analog Modulator and a Digital Modulator as well as two up converters.

The Analog Modulator provides pre-emphasis baseband processing as well as wideband FM modulation. The Wideband FM Modulator generates a modulated signal at the first intermediate frequency (IF 1) of the transmitter.

The 10 MHz bandwidth of the Wideband FM Modulator is sufficient for transmitting one composite television signal, an example of single channel per carrier (SCPC) transmission, or a number of multiplexed telephone connections using frequency division multiplexing (FDM)[1], an example of multiple connections per carrier (MCPC).

The **bit rate** R_b of a digital signal is the number of bits sent per second.

The Digital Modulator provides baseband processing and DQPSK (differential QPSK) modulation. The baseband section includes a 4-input TDM multiplexer, allowing for the time division multiplexing of up to four data streams at a maximum bit rate of 4 Mb/s each.[2] A fifth input is provided for the transmission of one unmultiplexed data stream of up to 20 Mb/s.

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[1] User-supplied equipment is required to multiplex and demultiplex the analog signals.
[2] The bit rate of DATA INPUT 4 is limited by the capacity of the serial USB port.

Digital satellite communications usually use a form of PSK (phase shift keying) modulation, such as QPSK (quadrature phase-shift keying). DQPSK is QPSK with differential encoding. These topics are covered in Unit 3.

A Scrambler is used to ensure frequent transitions in the data and to spread the power smoothly over the available bandwidth. A Clock & Frame Encoder is used with TDM to add transitions to the multiplexed data in order to ensure reliable clock recovery in the receiver as well as control bits for frame synchronization.

The digital data is applied to a DQPSK Modulator which generates a digitally modulated signal at the first intermediate frequency (IF 1) of the transmitter.

This intermediate frequency from either the Analog Modulator or the Digital Modulator is up converted in two stages by Up Converter 1 and Up Converter 2 in order to produce the RF Output signal. Up Converter 2 includes a Channel selector to select one of six carrier frequencies in the 11 GHz range. The antenna connected to the RF output transmits the uplink RF signal to the Satellite Repeater.

Up Converter 2 also has a Power Sensor (see *Power Sensors*).

The Earth Station Receiver

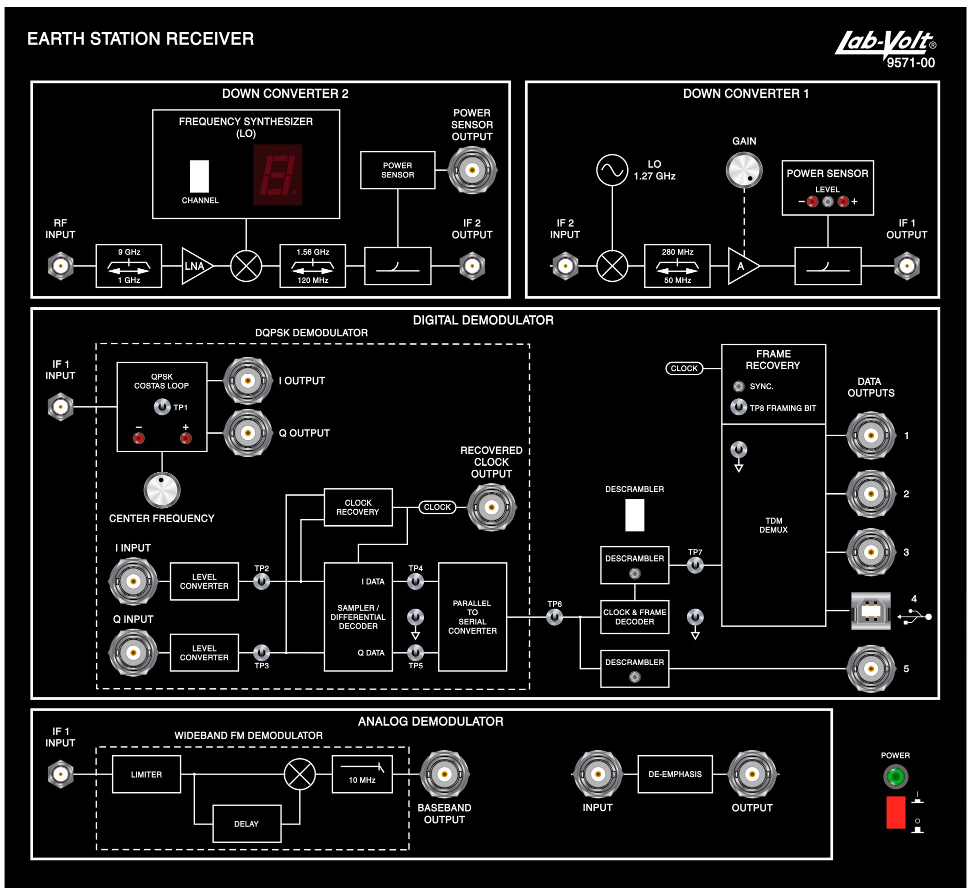


Figure 1-16. The Earth Station Receiver.

Earth Station Receiver, Model 9571, has an RF INPUT to which the receiving antenna is connected. The received downlink signal is down-converted in two stages. Down Converter 2 includes a Channel selector to select one of six carrier frequencies in the 9 GHz range. Down Converter 1 has a variable Gain control.

The output signal of Down Converter 1 is at the first intermediate frequency (IF 1) of the receiver.

Down Converter 1 and 2 each have a Power Sensor (see *Power Sensors*).

The Earth Station Receiver includes both an Analog Demodulator and a Digital Demodulator, both operating at IF 1. The Analog Demodulator provides wideband FM demodulation as well as baseband de-emphasis processing. The Digital Demodulator provides DQPSK demodulation as well as baseband processing and TDM demultiplexing of the demodulated data.

The differential QPSK digital modulation used in the Earth Station Transmitter produces a suppressed-carrier modulated signal. However, the demodulator in the Earth Station Receiver requires a copy of the transmitted carrier in order to demodulated the signal and recover the data. The QPSK Costas Loop in the Digital Demodulator of the receiver is a circuit that reconstructs the missing carrier and then decodes the data.

A Costas loop is a type of phased-locked loop often used to recover a carrier from a suppressed-carrier modulation signal, such as a QPSK. It includes an oscillator whose frequency and phase are controlled using a feedback loop. The feedback loop causes the oscillator to lock onto one of the phases present in the QPSK signal. Once the Costas loop is locked, it tracks that phase in order to keep the recovered carrier at the correct frequency and phase. The recovered carrier is a stable, sinusoidal waveform that is equivalent to the carrier signal used in the transmitter modulator. This recovered carrier is used to demodulate the digitally modulated signal.

The QPSK Costas Loop in the Earth Station Receiver recovers the carrier and demodulates the QPSK signal in order to recover the raw data that represents the differentially encoded symbols. This Costas loop is locked manually. The steps required to lock the Costas loop are given in the exercise Procedure.

The Satellite Repeater

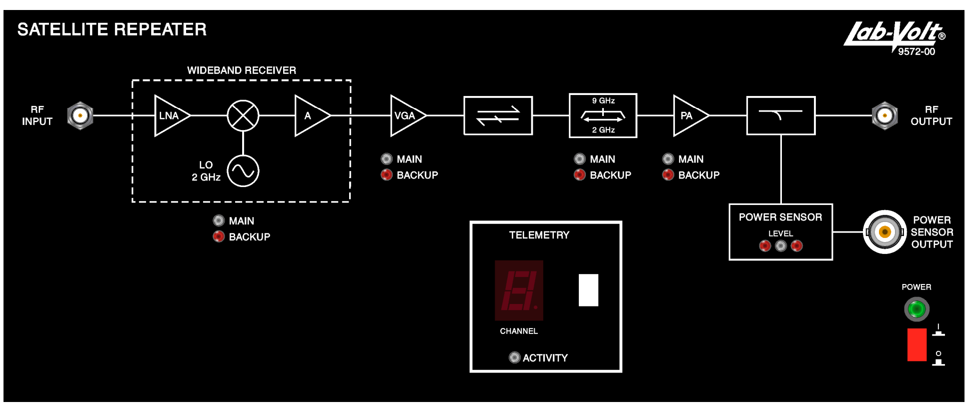


Figure 1-17. The Satellite Repeater.

The Satellite Repeater, Model 9572, uses separate uplink and downlink antennas. It contains a wideband receiver consisting of a low-noise amplifier (LNA), a down converter to shift the 11 GHz uplink signal down to the 9 GHz downlink range and an amplifier. This is followed by a telemetry-controlled

variable gain amplifier (VGA), an isolator, a band-pass filter, and a power amplifier (PA).

Several components of the Satellite Repeater are redundant, that is, there is a main and a backup unit. These are controlled by telemetry and are used in troubleshooting exercises. LEDs on the front panel show which unit is currently in use.

The Satellite Repeater also has a Power Sensor (see *Power Sensors*).

Power Sensors

To facilitate antenna alignment and measurement of RF power levels, the Earth Station Transmitter, the Earth Station Receiver, and the Satellite Repeater each have a Power Sensor. The Power Sensor converts the detected power level into a dc voltage. This voltage is available at the POWER SENSOR OUTPUT and/or is used to drive Level LEDs.

Users of conventional instruments can observe a relative indication of the power by connecting a dc voltmeter to the POWER SENSOR OUTPUT. If necessary, the measured voltage can be converted into an absolute power level in dBm by referring to Appendix E *Using Conventional* Instruments.

Users of the optional Telemetry and Instrumentation Add-On can read the power level directly in dBm using the virtual True RMS Voltmeter / Power Meter. For this, the POWER SENSOR OUTPUT is connected to one input of the Virtual Instrument, and the appropriate module is selected as the Source of the True RMS Voltmeter / Power Meter.

In addition to direct measurement, the power of the Satellite Repeater can also be measured remotely from the earth station, using telemetry. In this case, the power is displayed in dBm in the Telemetry tab of the Telemetry and Instrumentation application.

The Power Sensors and the spectrum analyzer indicate power differently. A spectrum analyzer shows the power of each individual frequency component present in the signal whereas the Power Sensor produces a dc voltage proportional to the sum of the powers of all frequency components in its range.

Since the spectrum analyzer displays only a limited range of frequencies at a time, some significant frequency components, including parasitic frequency components, may not be visible on the spectrum analyzer display. They will, however, be included in the Power Sensor reading. For this reason, and because of non-linearities in the two instruments, they may not indicate exactly the same power.

In addition, the Power Sensors are calibrated for the Channel D frequencies. When using other channels, the Power Sensors may give less accurate results.

For measuring the power of a single frequency component (e.g. the power of an unmodulated carrier signal), the spectrum analyzer will give more accurate results – the Power Sensor generally indicates a higher power than the spectrum analyzer does. For measuring the total power of a complex signal, however, the Power Sensor is much easier to use.

On the Satellite Repeater, the three Power Sensor Level LEDs provide a rough indication of the power at the RF OUTPUT, which is proportional to the power at the RF INPUT. The greater the power, the more LEDs are lit.

On the Earth Station Receiver, the three Power Sensor Level LEDs provide a rough indication of the power at the IF OUTPUT of Down Converter 1, which is proportional to the power at the RF INPUT and to the Gain adjustment. During normal operation, the Gain should be adjusted so the green LED is lit. The red – LED and + LED indicate that the power level is too low or too high, respectively.

The Telemetry and Instrumentation Add-On

The optional Telemetry and Instrumentation Add-On, Model 8093-1, provides an alternative to costly conventional instruments. This add-on, used in conjunction with the Telemetry and Instrumentation application, provides telemetry with the Satellite Receiver as well as a full suite of virtual instruments.

The Telemetry and Instrumentation Add-On consists of two modules:

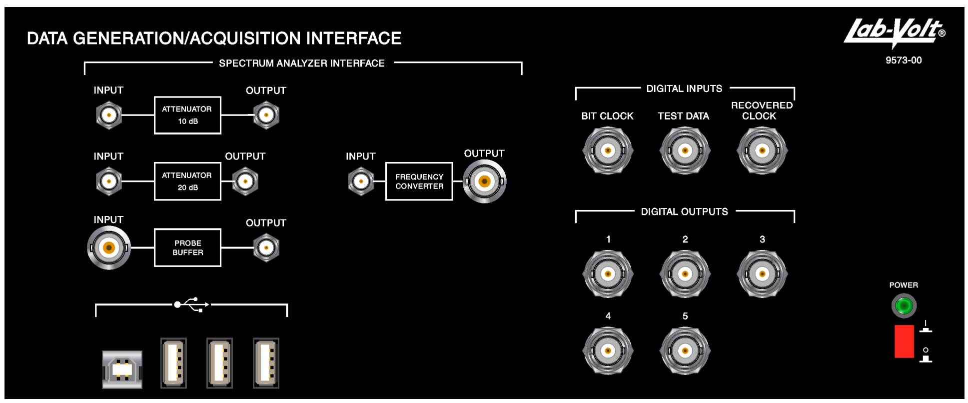


Figure 1-18. The Data Generation/Acquisition Interface.

The Data Generation/Acquisition Interface, Model 9573 provides a telemetry link with the Satellite Repeater. It also provides a Spectrum Analyzer Interface for use with the Virtual Instrument, Model 1250-A0, as well as Digital Inputs and Digital Outputs. Front panel USB connectors are provided for connecting this module to the host computer's USB port and for connecting other modules.

Figure 1-19. The Virtual Instrument Package.

The Virtual Instrument, Model 1250-A0, samples the analog signals applied to its two inputs in order to acquire data for the Telemetry and Instrumentation application. The high sampling rate (up to 1 GS/s) provides the Virtual Instrument with a 250-MHz bandwidth that is amply sufficient for the observation and analysis of the various signals in the Satellite Communications Training System. The Virtual Instrument unit also provides an output for the analog Waveform Generator.

This module requires a USB connection to the host computer. It can be connected to a USB connector on the Data Generation/Acquisition Interface or directly to a USB port on the computer.

The Telemetry and Instrumentation application, used in conjunction with the Telemetry and Instrumentation Add-On, provides a user interface for telemetry with the Satellite Receiver. It also provides the following virtual instruments:

- Oscilloscope
- Spectrum Analyzer
- Power Meter
- BER Tester
- Waveform Generator
- Three user-configurable Binary Sequence Generators (BSGs)

Refer to Appendix D *Using the Telemetry and Instrumentation Add-On* for information on connecting and operating the add-on and the software.

The exercises in this manual (except for procedure steps involving telemetry) can be performed using suitable conventional instruments and generators, instead of the Telemetry and Instrumentation Add-On (see List of Equipment Required at the beginning of this manual as well as Appendix E Using Conventional Instruments).

Symbols and abbreviations used on the module front panels

Table 1-5 and Table 1-6 show the Symbols and abbreviations used on the module front panels of the Satellite Communications Training System modules.

Table 1-5. Symbols used on the module front panels.

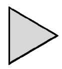
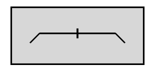
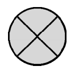
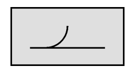
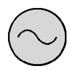
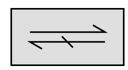
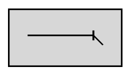
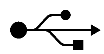
	Amplifier		Band-pass filter
	Mixer		Directional coupler
	Oscillator		Isolator
	Low-pass filter		USB connector

Table 1-6. Abbreviations and acronyms used on the module front panels.

A	amplifier
DEMUX	demultiplexer
DQPSK	differential QPSK
FM	frequency modulation
I	in-phase
IF	intermediate frequency
LNA	low-noise amplifier
LNB	low-noise block
LO	local oscillator
MUX	multiplexer
PA	power amplifier
Q	quadrature-phase
QPSK	quadrature phase-shift keying
RF	radio frequency
SYNC.	synchronization

TDM	time-division multiplexing
TP	test point
TTC	telemetry, tracking and command
VCO	voltage-controlled oscillator
VGA	variable-gain amplifier

Frequency converters

The operation of frequency converters is covered in more detail in Exercise 1-2.

Frequency converters are used in each of the RF modules in order to shift the frequency of a signal up or down. A frequency converter that shifts the frequency up is called an **up converter**. A **down converter** shifts the frequency down.

A frequency converter consists of a mixer and a local oscillator (LO) followed by a filter. The local oscillator used in a frequency converter can be either a fixed-frequency oscillator or a frequency synthesizer capable of producing a number of different frequencies.

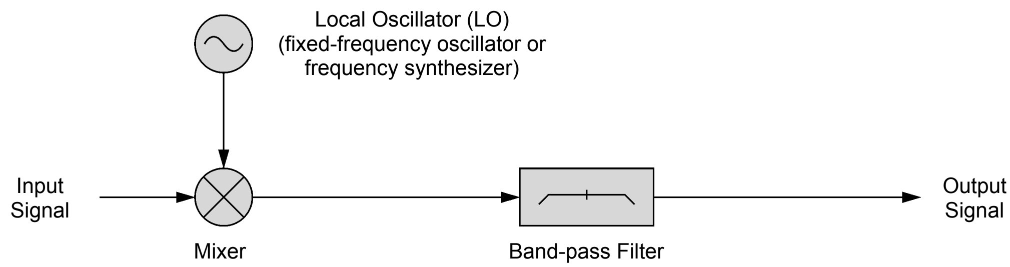


Figure 1-20. Frequency converter.

In the Satellite Communications Training System, the following naming convention is used:

- There are four frequency ranges in the Earth Station Transmitter and the Earth Station Receiver: RF, IF 2, IF 1, and the baseband. These frequency ranges compare as follows:

$$\text{RF} > \text{IF 2} > \text{IF 1} > \text{baseband frequencies}$$

- Up Converter 2 and Down Converter 2 operate at higher frequencies than Up Converter 1 and Down Converter 1

Figure 1-21 shows where these frequency ranges are used in the earth station modules.

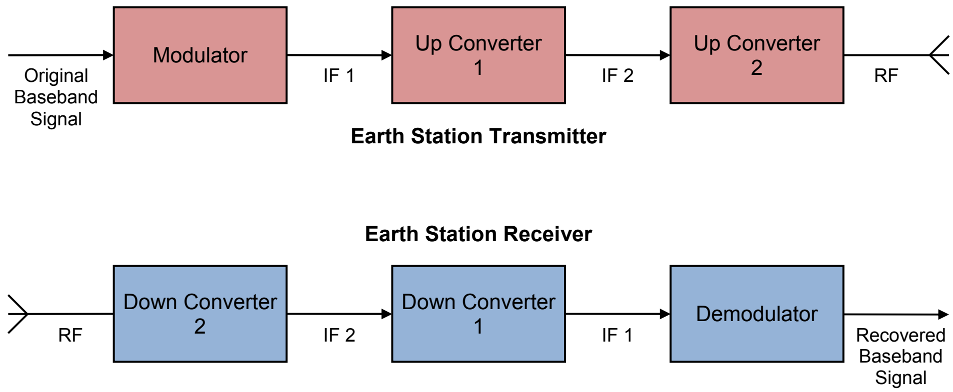


Figure 1-21. Frequency ranges in the Satellite Communications Training System.

Signal levels

Table 1-7 shows typical IF and RF signal levels in the Satellite Communications Training System. All levels are approximate and some depend on the distances between the transmitting and receiving antennas.

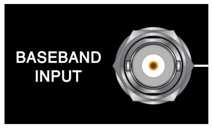
Table 1-7. Typical IF and RF signal levels.

Earth Station Transmitter	
Analog Modulator and Digital Modulator IF 1 OUTPUT	6 dBm
RF OUTPUT	3 dBm (varies according to selected Channel)
Satellite Repeater	
RF INPUT	–31 dBm
RF OUTPUT	–10 dBm
Earth Station Receiver	
RF INPUT	–48 dB
Analog Demodulator and Digital Demodulator IF INPUT	–2 dBm
Data Generation/Acquisition Interface	
Frequency Converter INPUT	–10 dB max.*

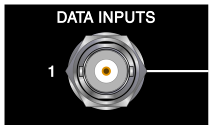
* Connect one of the Attenuators (10 dB or 20 dB) in series with the Frequency Converter if the applied signal level exceeds this maximum level.

CAUTION

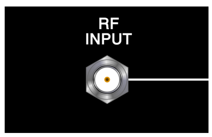
The inputs on the modules of the Satellite Communications Training System are NOT protected against misconnection. When using the system, be sure to observe the following precautions:



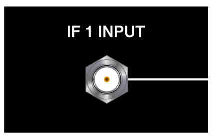
Analog inputs (BNC connectors in analog sections) are calibrated for voltages of 1.0 V pp. Voltages exceeding 5 V pp at analog inputs may damage the modules. Adjust the signal levels produced by all user-supplied equipment BEFORE connecting this equipment to the modules.



Digital inputs (BNC connectors in digital sections) are designed for TTL levels. Voltages exceeding standard TTL levels may damage the equipment.



RF INPUTs (SMA connectors marked “RF INPUT”) are designed for low level RF signals from an antenna. Never make a direct connection between an RF OUTPUT and an RF INPUT without using an appropriate attenuator. Excessive RF signal levels may damage the equipment.



IF INPUTs (SMA connectors marked “IF INPUT”) are designed for connection to IF OUTPUTs on the system modules.

When connecting external devices and instruments to the system modules, it is the user’s responsibility to make sure that all signal levels are compatible.

Safety with RF fields

When studying satellite communications systems, it is very important to develop good safety habits. Although microwaves are invisible, they can be dangerous at high levels or for long exposure times. The most important safety rule when working with microwave equipment is to avoid exposure to dangerous radiation levels.

Figure 1-22 shows radiation standards established by three regulatory organizations: the American Federal Communications Commission (FCC), the International Commission on Non-Ionizing Radiation Protection (ICNIRP), and Health Canada. There are two traces for each standard, one for people classed as RF and microwave exposed workers (solid line) and one for people who are not so classed, including the general public (broken line).

The standards are expressed in terms of plane-wave equivalent power density, that is, the average power per unit area normal to the direction of propagation. The figure also shows the maximum power density that can be produced by the Satellite Communications Training System using the supplied equipment.

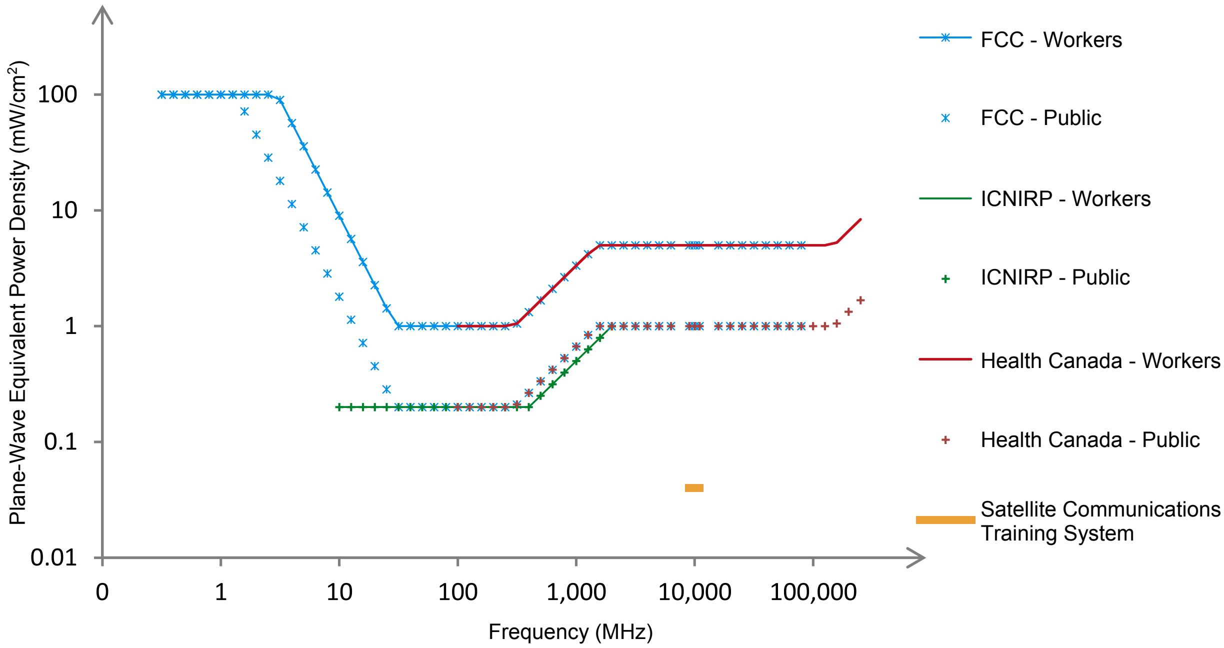


Figure 1-22. Radiation safety standards.

> Losses and aperture efficiency may reduce the actual power density by at least 25% to 50%.
>
> The power radiated by the Satellite Repeater is typically −10 dBm (0.1 mW) at 9 GHz.

Figure 1-22 shows that the radiation levels in the Satellite Communications Training System are too low to be dangerous. The highest power level in the system is at the RF OUTPUT of the Earth Station Transmitter and is typically 5 dBm (approximately 3.2 mW) at 11 GHz. The maximum possible plane-wave equivalent power density S using the supplied equipment would be obtained by connecting the Small-Aperture Horn Antenna to the RF OUTPUT of the Earth Station Transmitter. Neglecting losses and antenna aperture efficiency, the maximum power density would be approximately:

$$\begin{aligned} S &= P/A \\ &= 3.2\ \text{mW}/25\ \text{cm}^2 \\ &= 0.13\ \text{mW/cm}^2 \end{aligned} \tag{1-1}$$

where S is the maximum plane-wave equivalent power density
P is the output power of the transmitter
A is the front surface area of the horn antenna

In normal operation, the Large-Aperture Horn Antenna is connected to the Earth Station Transmitter. Neglecting losses and antenna aperture efficiency, the normal maximum power density is approximately:

$$\begin{aligned} S &= P/A \\ &= 3.2\ \text{mW}/76\ \text{cm}^2 \\ &= 0.04\ \text{mW/cm}^2 \end{aligned} \tag{1-2}$$

WARNING

For your safety, and to develop safe work habits, avoid looking directly into the antennas when the Earth Station Transmitter or the Satellite Repeater is on.

Procedure Outline

The Procedure is divided into the following sections:

- System startup
- Optimizing antenna alignment
- Analog communications
- Transmitting analog signals from external sources
- Digital communications
- Transmitting digital signals
- Data transfer

Procedure

This procedure is designed to familiarize you with the basic operation of a satellite communications system. It will also allow you to become familiar with the Satellite Communications Training System and with the virtual or conventional instruments you will be using throughout the courseware.

System startup

1. If not already done, set up the system and align the antennas visually as shown in Appendix B.

2. Make sure that no hardware faults have been activated in the Earth Station Transmitter or the Earth Station Receiver.

   Faults in these modules are activated for troubleshooting exercises using DIP switches located behind a removable panel on the back of these modules. For normal operation, all fault DIP switches should be in the “O” position.

3. Turn on each module that has a front panel Power switch (push the switch into the I position). After a few seconds, the Power LED should light.

4. If you are using the optional Telemetry and Instrumentation Add-On:

   - Make sure there is a USB connection between the Data Generation/Acquisition Interface, the Virtual Instrument, and the host computer, as described in Appendix B.
   - Turn on the Virtual Instrument using the rear panel power switch.

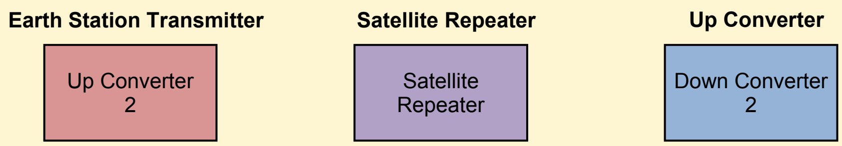
     If the TiePieSCOPE drivers need to be installed, this will be done automatically in Windows 7 and 8. In Windows XP, the Found New Hardware Wizard will appear (it may appear twice). In this case, do not connect to Windows Update (select *No, not this time* and click Next). Then select *Install the software automatically* and click Next.

- Start the Telemetry and Instrumentation application. In the Application Selector, do not select *Work in stand-alone mode*.

If the Telemetry and Instrumentation application is already running, exit and restart it. This will ensure that no faults are active in the Satellite Repeater.

Connection Diagrams

Connections are shown in this manual using diagrams that contain colored blocks. These blocks correspond to functional blocks or sections shown on the front panels of the modules. Color is used to identify the module, as shown in the examples below:

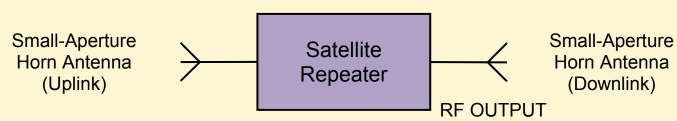


Other colors are used to identify the modules of the optional Telemetry and Instrumentation Add-On.

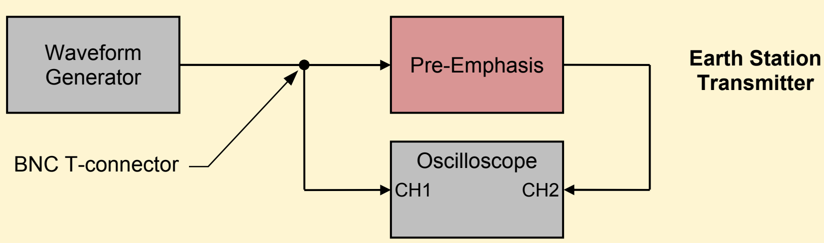
The type of cable required for each connection depends on the type of connectors used on the modules. Microwave cables have SMA connectors whereas low-frequency cables have BNC connectors.

Long microwave cables are usually used to connect the antennas, for flexibility in placing the antennas, although short microwave cables can be used if desired.

Small-Aperture Horn Antennas are usually connected to the Satellite Repeater. *Large-Aperture Horn Antennas* are usually connected to the Earth Station Transmitter RF OUTPUT and the Earth Station Receiver RF INPUT.



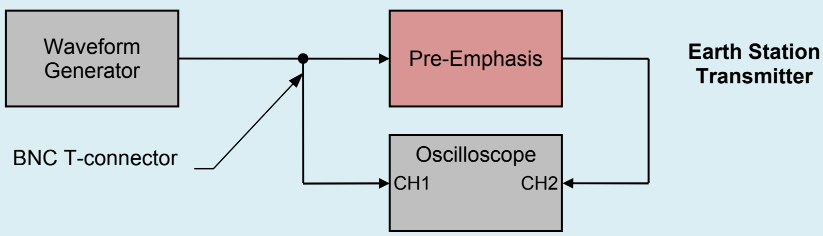
Grey blocks are instruments. These can be either conventional instruments provided by the user or virtual instruments included in the optional Telemetry and Instrumentation Add-On.



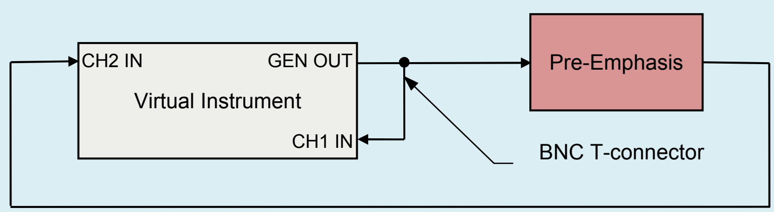
In these connection diagrams, the names of the inputs and outputs of the blocks are given where necessary for clarity or in order to prevent ambiguity. For example, since the Pre-Emphasis block on the Earth Station Transmitter has only one input and one output, these outputs may not be named. As the Satellite Repeater has two outputs, however, the output to be used is always named.

Using the Telemetry and Instrumentation Add-On

To assist those who are using the optional Telemetry and Instrumentation Add-On, instead of conventional instruments, additional information may be provided showing exactly how to make the connections. For example, consider the circuit shown below:



The waveform generator and the oscilloscope can be implemented using the Telemetry and Instrumentation Add-On, as shown in the following figure. The generated waveform is available at the GEN OUT connector of the Virtual Instrument. On the same module, the inputs CH1 IN and CH2 IN act as the inputs to the virtual Oscilloscope.



In the Telemetry and Instrumentation application, the virtual Waveform Generator is always available and does not need to be started. It is configured using the Waveform Generator settings, for example:

- Waveform Generator
  Function .... Sine
  Frequency .... 1000 kHz
  Output Level .... 0.1 V

Because the Waveform Generator uses digital circuits, it may not be possible to set the Frequency to the exact frequency desired. For example, after entering 1000 kHz, the value changes to 999.999 kHz.

To use the virtual Oscilloscope, click the icon, or choose *Oscilloscope* in the Instruments menu. Then set the Source setting for each channel used:

- Oscilloscope Settings
  Channel 1 (X)
  Source .... CH1 IN
  Channel 2 (Y)
  Source .... CH2 IN

Set the other Oscilloscope settings as required.

For detailed information on connecting and using the virtual instruments, refer to Appendix D Using the Telemetry and Instrumentation Add-On *or to the Help menus in the Telemetry and Instrumentation application.*

Optimizing antenna alignment

This section shows an easy way to optimize alignment of the uplink and downlink antennas. You can use this method at any time during normal operation without modifying the current connections.

5. Make the connections shown in Figure 1-23.

In Figure 1-23, there is no connection to the input of the modulator. This procedure will work, however, with or without an input signal to the modulator.

If desired, the DQPSK Modulator can be used instead of the Wideband FM Modulator to provide the IF signal that is applied to Up Converter 1.

Although the voltmeter / power meter is not essential for aligning the antennas, it is suggested that you use it the first time you optimize the alignment. After that, you will be able to optimize the alignment by referring only to the Level LEDs on the modules.

The connections shown in Figure 1-23 cause an RF signal to be transmitted by the Earth Station Transmitter, relayed by the Satellite Repeater, and received by the Earth Station Receiver.

On the Satellite Repeater, the three Power Sensor Level LEDs provide a rough indication of the power at the RF OUTPUT, which is proportional to the power at the RF INPUT. The greater the power, the more LEDs are lit.

On the Earth Station Receiver, the three Power Sensor Level LEDs provide a rough indication of the power at the IF OUTPUT of Down Converter 1, which is proportional to the power at the RF INPUT and to the Gain adjustment. During normal operation, the Gain should be adjusted so the green LED is lit. The red – LED and + LED indicate that the power level is too low or too high, respectively.

CAUTION

Handle microwave cables with care, especially when making or removing connections. Make sure the connectors remain free of dust. Tighten the SMA connectors by hand until they are snug. Do not over tighten!

For further information on the care of microwave cables, refer to Appendix C.

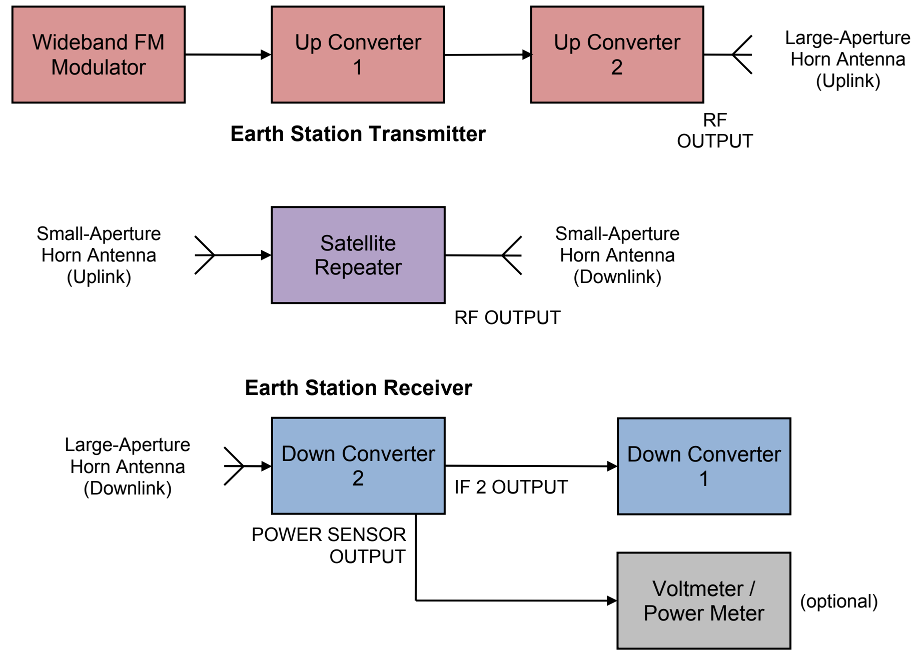
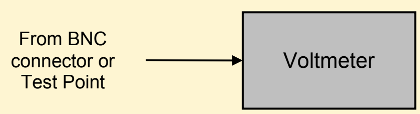


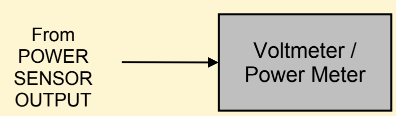
Figure 1-23. Connections for antenna alignment.

Measuring voltage and power

A voltmeter or multimeter can be connected to any BNC connector or test point to measure the voltage present. In this case, the instrument is shown in connection diagrams as a Voltmeter.



When connected to the POWER SENSOR OUTPUT of a module, the displayed voltage provides a relative indication of the power level. In this case, the instrument is shown in connection diagrams as a voltmeter / power meter.



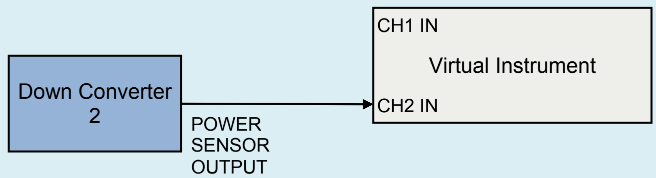
If you are using a conventional instrument, the voltage from a POWER SENSOR OUTPUT can be converted to an absolute power level by referring to Appendix E *Using Conventional Instruments*.

When aligning the antennas, it is not necessary to know the absolute power level, a relative power level is sufficient. You can simply orient the antennas to maximize the dc voltage at the POWER SENSOR OUTPUT of the receiver.

Measuring power using the Telemetry and Instrumentation Add-On

The virtual True RMS Voltmeter / Power Meter measures voltage. When connected to a POWER SENSOR OUTPUT, it can automatically convert the measured dc voltage into a power level in dBm.

For example, in order to measure the power at Down Converter 2 of the receiver, the POWER SENSOR OUTPUT of the receiver must be connected to one of the input channels of the Virtual Instrument. The figure below shows it connected to CH2 IN:



To start the True RMS Voltmeter / Power Meter, click in the toolbar of the Telemetry and Instrumentation application or choose *Instruments* ▶ *True RMS Voltmeter / Power Meter*.

In the True RMS Voltmeter / Power Meter, make the following settings:

- Input
  Source ....(select the input channel used)
  Module ....(select the module)
  Mode ....Power Meter

Click the button or select *Continuous Refresh* in the *View* menu in order to make a continuous measurement. Doing this again stops the measurement.

In the Power Meter mode, the True RMS Voltmeter / Power Meter converts the dc voltage at any POWER SENSOR OUTPUT directly into a power reading in dBm.

Each of the three RF modules has a Power Sensor. Since each Power Sensor has a different power/voltage characteristic, it is important to set the Module setting correctly.

You can enlarge the display of the True RMS Voltmeter / Power Meter by enlarging its window. This will make it more visible when aligning the antennas on the Satellite Repeater.

6. Make sure the two uplink antennas are positioned and aligned so they point directly at each other. Do the same with the downlink antennas.

   On the Earth Station Receiver, set the Gain control to the mid position.

   Turn the antenna connected to the Earth Station Transmitter to the right or to the left. Note that the three Power Sensor LEDs on the Satellite Repeater provide a relative indication of the received power level. The greater the power, the more LEDs are lit. If you have connected the voltmeter / power meter to the Earth Station Receiver, this will also provide a relative indication of the power. Align the two uplink antennas (on the transmitter and on the repeater) to maximize the power.

Turn the antenna connected to the Earth Station Receiver to the right or to the left. Note that the three Power Sensor LEDs on the Earth Station Receiver provide a relative indication of the received power level. If you have connected the voltmeter / power meter, this will also provide a relative indication of the power. Align the two downlink antennas (on repeater and on the receiver) to maximize the power.

Adjust the Gain control on the Earth Station Receiver so that the green Level LED is lit.

A good way to align an antenna is to find two angular positions, on either side of the maximum position, where the indicated power levels are approximately equal, and then to point the antenna mid-way between these two positions. This method can be used with the Satellite Communications Training System and with parabolic antennas receiving signals from geostationary satellites.

Because of the low power levels at the Earth Station Receiver, it is quite sensitive to reflections for the RF signal. You may notice that the Level LEDs change when you move near the receiver. This is normal.

With the Satellite Communications Training System and normal distances, antenna alignment is not critical. With real satellites, however, it is essential that antenna alignment be optimized because of power limitations and the great distances involved.

Analog communications

7. Make the connections shown in Figure 1-24.

CAUTION

Analog inputs (BNC connectors in analog sections) are calibrated for voltages of 1.0 V pp. Voltages exceeding 5 V pp at analog inputs may damage the modules. Adjust the signal levels produced by all user-supplied equipment BEFORE connecting this equipment to the modules.

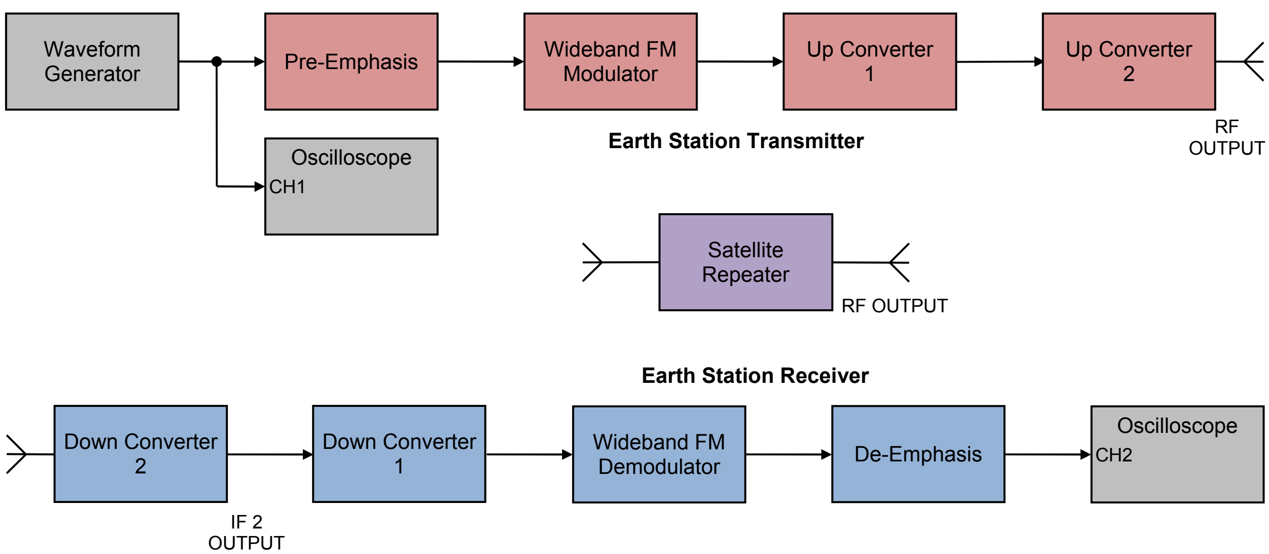


Figure 1-24. Connections for transmitting an analog signal.

In order to simplify the connection diagrams used in this manual, the CH1 and CH2 inputs of the oscilloscope may be shown in two different blocks, as in Figure 1-24.

The Satellite Repeater is not always shown explicitly in connection diagrams. It is always used, however, to relay the RF signal from the Earth Station Transmitter to the Earth Station Receiver.

For technical reasons, the De-Emphasis block inverts the polarity of the signal. Although this may be apparent when observing the signals on an oscilloscope, it has no effect on analog transmission except for certain types of signals, such as video signals, where the polarity is important.

Using the Virtual Instruments

To open a virtual instrument in the Telemetry and Instrumentation application, choose a command in the *Instruments* menu or click the corresponding button on the toolbar.

Three analog instruments are provided:

- Oscilloscope
- Spectrum Analyzer
- True RMS Voltmeter / Power Meter

One digital instrument is provided:

- Bit Error Ratio Tester

All virtual instruments have a Source setting which indicates the source of the signal being measured or displayed. In some cases, there is only one possible source.

- For analog instruments, the Source can be CH1 IN or CH2 IN (inputs on the Virtual Instrument, Model 1250-A0), or Off to disable the input.
- For the BER Tester, the Test Data Source is the Test Data Input (a digital input on the Data Generation/Acquisition Interface).

Only one analog instrument can be active at the same time. The status bar indicates the current state of the instrument.

Each instrument has two toolbar buttons used to select the refresh mode: *Single Refresh* and *Continuous Refresh*. To activate an instrument, click on the instrument and then click either of these buttons. *Continuous Refresh* should be used to continuously monitor a signal.

Refer to Appendix D and the on-line help for information on configuring and using the virtual instruments.

8. On the Earth Station Transmitter, select a Channel in Up Converter 2. On the Earth Station Receiver, select the same Channel in Down Converter 2.

If more than one earth station is being operated in the same laboratory, each earth station should use a different channel.

9. Vary the frequency and the function of the waveform generator. Observe the transmitted and received waveforms on the oscilloscope. Figure 1-25 shows an example of what you might observe.

The instrument screens shown in this manual were taken using the Telemetry and Instrumentation Add-On. If you are using conventional instruments, the displays will be different. In some cases, the settings used are shown in a condensed form in the margin.

Oscilloscope Settings:
Channel 1 Source .... CH1 IN
Channel 1 Scale .... 1 V/div
Channel 2 Source .... CH2 IN
Channel 2 Scale .... 1 V/div
Time Base .... 1 µs/div
Trigger Source .... Ch 1
Trigger Level .... 0 V
Trigger Slope .... Rising

Generator Settings:
Waveform Generator
Function .... Sine
Frequency .... 1000 kHz
Output Level .... 1 V

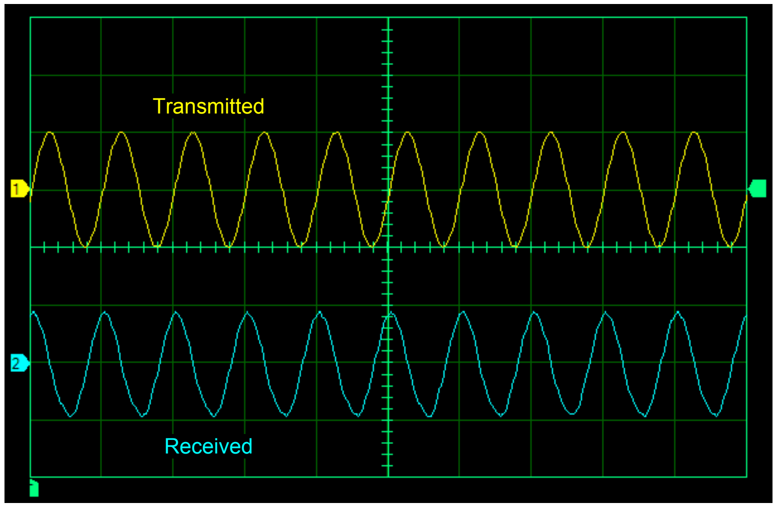


Figure 1-25. Transmitted and received sine wave.

Does the received waveform resemble the transmitted waveform?

Yes, the received waveform resembles the transmitted waveform, except that it is inverted by the De-emphasis block. There may also be some distortion that is mainly apparent when transmitting waveforms with very high frequency components, such as a square wave.

Examine the front panel of the Satellite Repeater. What type of repeater is this? What is the main difference between this type of repeater and the other main type?

The Satellite Communications Training System has a transparent repeater. A transparent repeater does not demodulate the uplink signal. Instead, it simply receives the uplink signal, shifts it to the downlink frequency, amplifies it, and retransmits it. A regenerative repeater, on the other hand, demodulates the uplink signal to recover the baseband signals, carries out baseband signal processing and switching, and then remodulates the baseband signals before transmission over the downlink.

10. On the transmitter only, select a different Channel while observing the oscilloscope. This changes the frequency of the local oscillator (LO) used to up convert the IF 2 signal to the RF OUTPUT frequency.

What effect does this have on the frequency of the uplink signal? Does the receiver now receive the downlink signal?

The frequency of the uplink signal changes. Since the Channel has not been changed on the receiver, the receiver does not recover the downlink signal, except for a small vestige that may be visible on the oscilloscope, especially when transmitting waveforms with very high frequency components, such as a square wave.

Change the Channel on the receiver to match the new Channel selected on the transmitter. What effect does this have?

This tunes the Down Converter 2 LO on the receiver to receive the downlink signal at the frequency corresponding to the new channel. As a result, the receiver now receives the downlink signal.

Is any change on the repeater required to reestablish the link at the new frequencies? Explain.

No. Because the transponder bandwidth covers the carrier frequencies of all channels used by the system, no adjustment on the repeater is required in order to use a different channel.

Does the repeater transmit the downlink signal at the same frequency as the uplink signal? Explain.

Refer to the Discussion of this exercise. The frequencies of the RF signals will be measured in a later exercise.

No, the repeater shifts the uplink signal to a lower frequency before retransmitting it over the downlink. This is necessary to prevent the strong downlink signal from interfering with the weak uplink signal.

Transmitting analog signals from external sources

11. Use the system to transmit an analog signal from an external source over the satellite link. Any analog signal in the frequency range of approximately 10 Hz to 10 MHz can be used, providing the signal level is compatible with the analog inputs on the Earth Station Transmitter.

CAUTION

Analog inputs (BNC connectors in analog sections) are calibrated for voltages of 1.0 V pp. Voltages exceeding 5 V pp at analog inputs may damage the modules. Adjust the signal levels produced by all user-supplied equipment BEFORE connecting this equipment to the modules.

The cables and adapters included in the Accessories may be used to connect external devices to the Satellite Communications System. User-supplied adapters may also be used where necessary.

Except for video devices, connect the devices as follows:

- The source device should be usually connected to the Pre-Emphasis INPUT, in place of the waveform generator in Figure 1-24. The signal from the source device will be transmitted over the satellite link to the receiver.
- If a suitable device is available to monitor the received signal, it should be connected to the De-Emphasis OUTPUT of the receiver. The oscilloscope or the spectrum analyzer can also be connected to this output, using a BNC T-connector if necessary.

When transmitting video signals, do not use the Pre-Emphasis/De-Emphasis blocks. (Using Pre-Emphasis in the transmitter will result in excessive deviation at the Wideband FM Modulator. Using De-Emphasis in the receiver inverts the demodulated signal.) Instead, connect external video devices as shown in Figure 1-26.

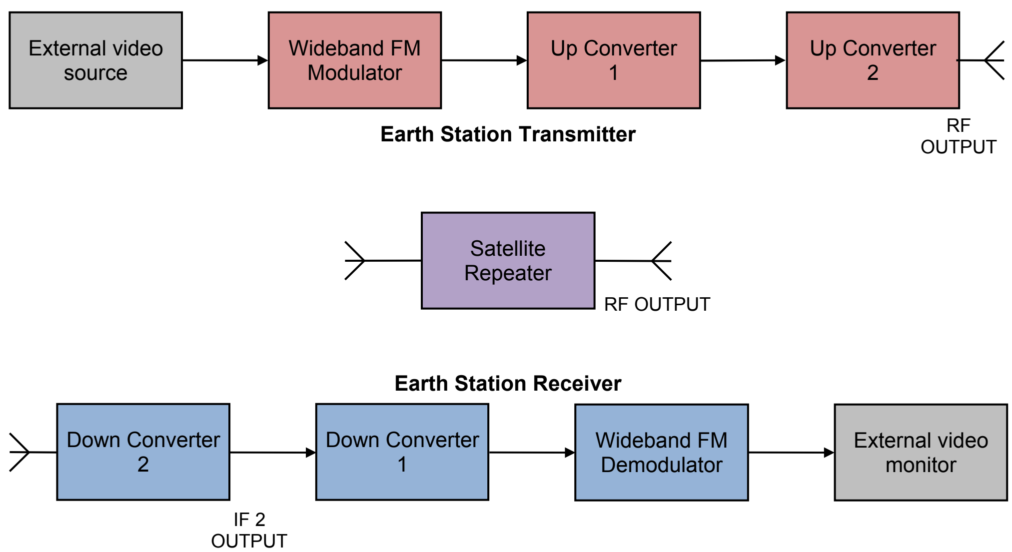


Figure 1-26. Connections for video transmission.

Table 1-8 provides examples of the types of analog signals that can be transmitted over the system along with suggested signal sources.

Table 1-8. Analog signals.

Signal	Typical Frequencies	Source Devices	Monitor Devices
Baseband audio signal	20 Hz to 20 kHz max.	• Microphone and preamplifier • Radio • Mp3 player • Computer (audio output) • Dual Function Generator, Model 9402*	• Audio amplifier • Headphones • Computer (audio input) • Power Supply / Dual Audio Amplifier, Model 9401

Baseband video signal	DC to 4.2 MHz	• Composite TV output (yellow RCA connector) on:
		  • a digital camera
		  • a camcorder
		  • a VCR
		  • a DVD player
			• TV with composite video input (yellow connector)
			• Computer and a USB or PCI TV tuner card that has a composite video input

AM signal	Approx. 20 kHz to 30 kHz bandwidth in the range 520 kHz to 1610 kHz	• The AM/DSB/SSB Generator, Model 9410* and a suitable audio source • RF signal generator with AM modulation and a suitable audio source	• The AM/DSB Receiver, Model 9411* and Power Supply / Dual Audio Amplifier, Model 9401

Best results are obtained when the level of the signal applied to the WIDEBAND FM MODULATOR is approximately 1 V_{pp}. When using a microphone as a source device, a preamplifier will likely be required.

**Models 9402, 9410 and 9411 require the Power Supply / Dual Audio Amplifier, Model 9401 to operate. These models are part of the Analog Communications Training System, Model 8080.*

What type of connection is established over this satellite link? What type of connection is required for two-way communication?

A simplex connection. A duplex connection is required for two-way communication.

What type of modulation is presently being used? Explain.

The modulation being used is wideband FM, a type of analog modulation frequently used in satellite communications. Analog modulation is used because the baseband signal is an analog signal.

How is the output signal of the modulator transformed before transmission?

The output signal of the WIDEBAND FM MODULATOR is shifted up in frequency in two stages, by Up Converter 1 AND Up Converter 2, before transmission.

Digital communications

The QPSK Costas Loop in the Digital Demodulator

This section shows what happens as the Costas loop on the Earth Station Receiver locks and also shows how to lock it manually.

Locking the QPSK Costas loop

All forms of PSK modulation, including QPSK and DQPSK, are suppressed-carrier types of modulation. For demodulation to occur, the QPSK Costas loop in the Earth Station Receiver must be locked onto the received QPSK signal in order to recover the suppressed carrier. Once the loop is locked, a feedback circuit keeps it locked, causing it to track the signal in order to maintain the recovered carrier at the correct frequency and phase.

The QPSK Costas loop contains a VCO whose frequency and phase are controlled by the voltage at the output of an integrator. This voltage can be measured at TP1 on the Earth Station Receiver. The Center Frequency control on the receiver sets one of the integrator input voltages. This control is used in locking the loop.

There is no indicator on the Earth Station Receiver to directly indicate whether the Costas loop is locked or not. There are, however, three indirect indications that the Costas loop is locked:

- The Frame Recovery section of the TDM DEMUX in the receiver includes a Sync. LED. This LED lights when the framing bits generated by the Clock & Frame Encoder on the transmitter have been recognized. Since this can only occur when the Costas loop is locked, the Sync. LED can serve as an indicator of the locked condition, providing the Clock & Frame Encoder on the transmitter is turned on.
- Digital data from the transmitter is correctly demodulated by the receiver only when the Costas loop is locked. This is true whether the Clock & Frame Encoder and Decoder are on or off.
- When the Costas loop is locked, the voltage at TP1 of the receiver remains fixed at a certain level, except for slight fluctuations. You can determine the locked-condition voltage by measuring the voltage at TP1 when the Costas loop is known to be locked.

The QPSK Costas loop is designed to be locked manually, although under certain conditions, it may lock without manual intervention.

12. Make the connections shown in Figure 1-27.

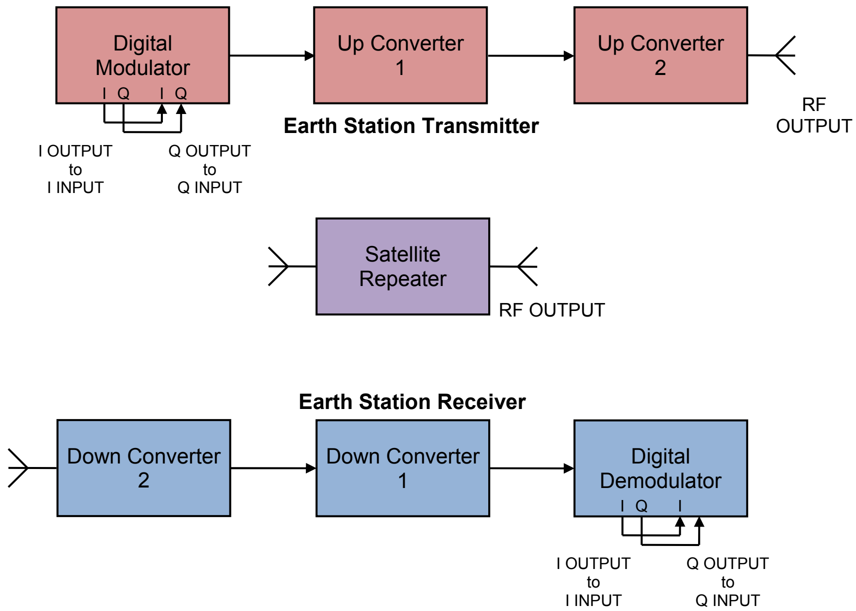


Figure 1-27. Minimal connections for locking the QPSK Costas Loop.

Figure 1-27 shows the minimal connections required for this step. The QPSK Costas Loop can also be locked while other connections are made to the Digital Modulator and the Digital Demodulator.

The QPSK Costas loop is designed to work with a modulated signal that contains all possible phases, such as one carrying relatively complex data. When no data source is connected to the transmitter, turning on the Scrambler will ensure that all phases are present in the modulated signal.

13. On the Earth Station Transmitter, make the following adjustments:

Channel .... any
Data Source.. any
Scrambler .... On
Clock & Frame Encoder .... On

On the Earth Station Receiver, make the following adjustments:

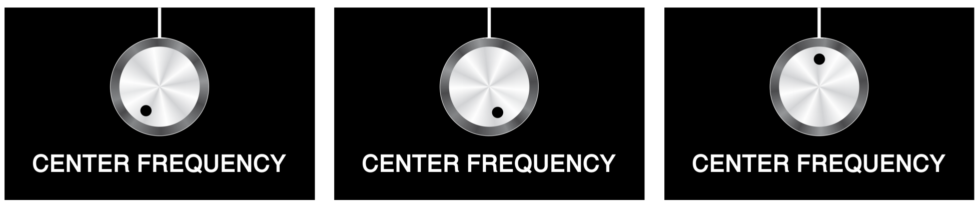
Channel .... same as transmitter
Descrambler .... On
Center Frequency.. mid position
Gain.. Adjust so the green Level LED is lit.

14. After making these adjustments, the Sync. LED may go on after a few seconds, indicating that the Costas loop is locked.

If the Sync. LED does not go on:

- Turn the Center Frequency knob of the QPSK Costas Loop to either extreme position (see Position 1 in Figure 1-28, for example).
- After a few seconds, turn the knob to the other extreme position (see Position 2). Wait until the Sync. LED in the Frame Recovery section of the TDM DEMUX lights. When it lights, the Costas Loop is locked.
- Turn the knob to the mid position (Position 3).

When the Costas loop is locked, the Center Frequency knob has no effect. However, it is preferable to leave it in the mid position.



Position 1 If the Sync. LED is off, the TP1 voltage is falling.	Position 2 If the Sync. LED is off, the TP1 voltage is rising.	Position 3

Figure 1-28. Locking the Costas Loop on the receiver.

The – and + LEDs in the QPSK Costas Loop provide a rough indication of the voltage at TP1. When the – LED is lit, the voltage is too low to allow the loop to lock; when the + LED is lit, the voltage is too high.

15. The Costas loop is easy to lock using the method shown in Step 14. However, it is useful to examine the signals before and after the loop reaches the locked condition.

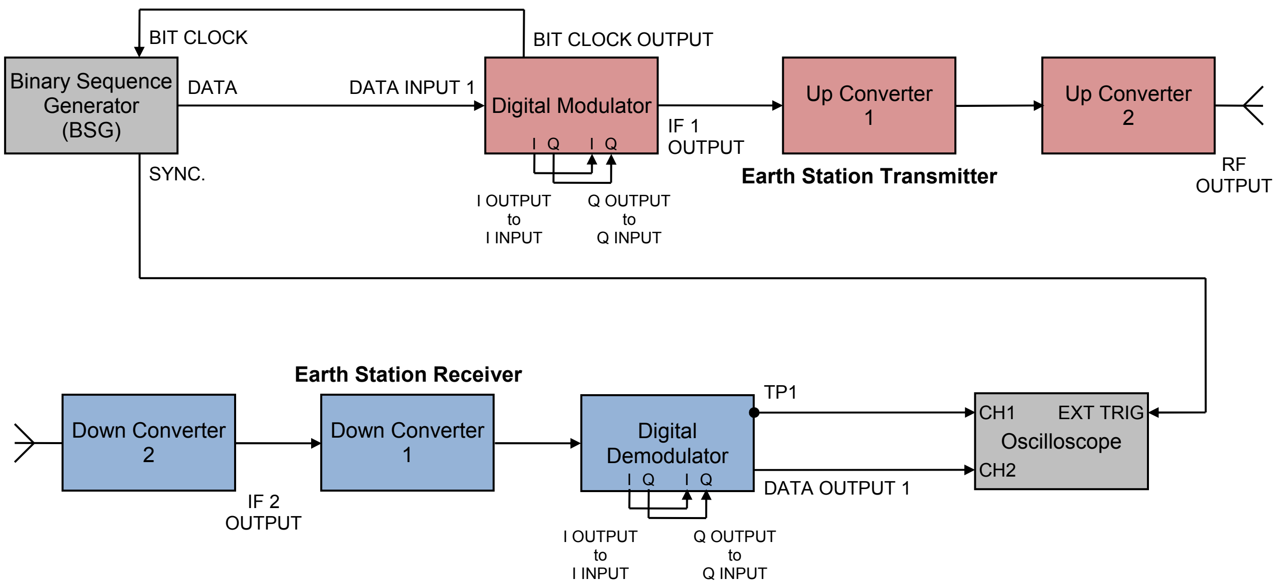


Figure 1-29. Connections for the Costas loop (Satellite Repeater used but not shown).

The following steps will allow you to observe the signals:

1. Make the connections shown in Figure 1-29. In this figure, DATA INPUT 1 on the transmitter and DATA OUTPUT 1 on the receiver are used. However, any other corresponding input-output pair can be used.

   A probe is used to connect test point TP1 of the Earth Station Receiver to the oscilloscope. Set the switch on the probe to the x1 position.

   You can use a conventional dc voltmeter, rather than the oscilloscope, to monitor the voltage at TP1.

   When connecting a probe to a test point, be sure to connect the ground clip to a ground loop on the module front panel.

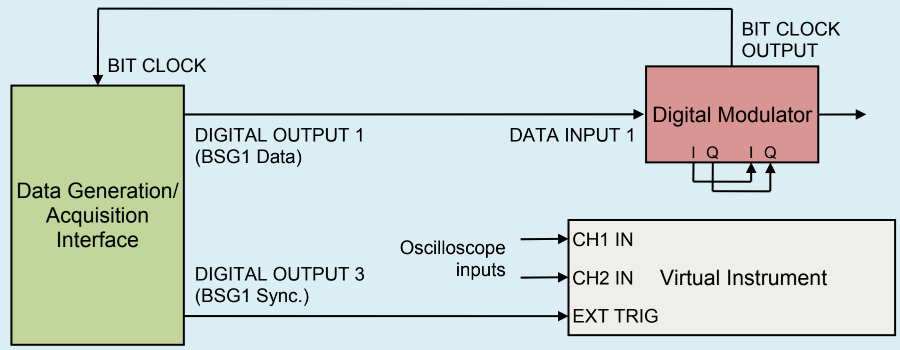
   Configure the binary sequence generator (BSG) to produce a pseudo-random sequence. Set n and the Bit Rate as desired (for example, set n to 4 and the Bit Rate to 100 000 bit/s).

   Set the time base of the oscilloscope to display roughly one or two bits per division (for a bit rate of 100 000 bit/s, you could use a time base of 20 µs/div). Trigger the oscilloscope on the EXT TRIG signal.

A pseudo-random sequence is not truly random but repeats after *L* bits. The sequence length $L = 2^n - 1$ where *n* is the number of shift registers used to generate the sequence.

Using the Telemetry and Instrumentation Add-On

The Binary Sequence Generator and the oscilloscope in Figure 1-29 can be implemented using the Telemetry and Instrumentation Add-On, as shown below:



The Telemetry and Instrumentation application has three Binary Sequence Generators: BSG1, BSG2 and BSG3. Each BSG is fully configurable and generates a repeating binary sequence according to the following settings:

BSG Setting	Value	Result
Generation Mode	Pseudo-Random	Generates a pseudo-random binary sequence whose length is determined by the n setting.
	User-Entry	Generates a user-defined sequence up to 32 bits long.
	BER Test Data	Generates a predetermined sequence used for measuring bit error ratio.
n	2 to 16	The n value that determines the length L in bits of the pseudo-random binary sequence where $L = 2^n - 1$.
Bit Rate	10 000 to 20 000 000	The number of bits per second.

Make the following adjustments in the Telemetry and Instrumentation application:

Digital Output Settings:

- ⊡ Digital Output 1
  Source BSG1
  Signal....................... Data
- ⊡ Digital Output 3
  Source BSG1
  Signal....................... SYNC.

Generator Settings:

- ⊡ Binary Sequence Generator (BSG) 1
  Generation Mode...... Pseudo-Random
  n .... 3 or more
  Bit Rate..................... 100 000 bit/s

On the virtual Oscilloscope, set the Trigger Source to EXT. When using an external trigger source, it may be easier to trigger on the falling slope.

2. On the Earth Station Transmitter, make the following adjustments:

   Channel .... any
   Data Source... any
   Scrambler .... On or Off
   Clock & Frame Encoder .... On

   On the Earth Station Receiver, make the following adjustments:

   Channel .... same as transmitter
   Descrambler .... same as Scrambler on transmitter
   Center Frequency... mid position
   Gain... Adjust so the green Level LED is lit.

   Because a pseudo-random binary sequence is being transmitted, the Scrambler and Descrambler can both be either On or Off.

3. Observe the DATA OUTPUT 1 signal on the oscilloscope. If the Costas loop is locked, you will see the recovered data. Otherwise, an apparently random signal will be displayed, as shown in Figure 1-30.

Oscilloscope Settings:
Channel 1 Scale ....2 V/div
Channel 2 Scale ....5 V/div
Time Base............................20 μs/div
Trigger Source ....EXT
Trigger Level.............................. 1.6 V
Trigger Slope ....Rising

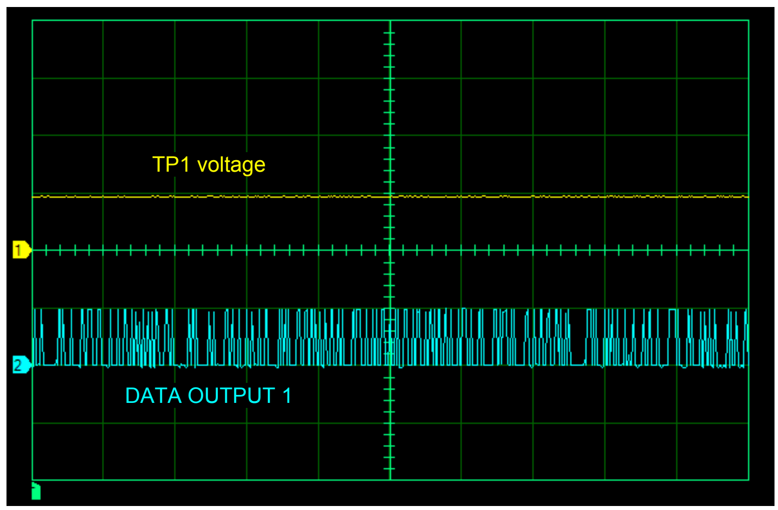


Figure 1-30. TP1 voltage and DATA OUTPUT 1 (Costas loop unlocked).

4. Change the CHANNEL on the receiver (select a channel that is not being used by another transmitter in the same laboratory). On the receiver, the POWER SENSOR "–" LED lights to show that there is no received signal and the Sync. LED will be off. The oscilloscope will display an apparently random signal.

5. Observe dc voltage at TP1 on the oscilloscope. On the Earth Station Receiver, turn the Center Frequency knob fully clockwise and wait. The Center Frequency knob sets the voltage at one input of an integrator in the feedback loop. The dc voltage at TP1 is the output voltage of the integrator. This dc voltage will gradually rise to its maximum value. The "+" LED in the QPSK Costas Loop will light when the dc voltage is above the range where locking is possible.

6. On the Earth Station Receiver, slowly turn the Center Frequency knob counterclockwise. When the knob is below the center position, the

dc voltage shown on the oscilloscope will begin to fall. Turning the knob further beyond the center position makes the voltage fall more rapidly. Eventually, the dc voltage will reach its minimum value. The "–" LED in the QPSK Costas Loop will light when the dc voltage is below the range where locking is possible.

If the dc voltage was allowed to rise too high, it may be difficult to reduce it using the Frequency Control. In this case, temporarily reduce the Gain on Down Converter 1.

7. On the Earth Station Receiver and the Earth Station Transmitter select the same Channel. The green POWER SENSOR Level LED on the Earth Station Receiver should be lit.

When viewing a sequence of bits on the oscilloscope in the normal display format, a low level corresponds to 0 and a high level corresponds to 1.

8. Turn the Center Frequency knob to the maximum position (see Position 2 in Figure 1-28). The dc voltage will begin to rise. Eventually, the Costas loop will lock and the Sync. LED will light. At this moment, the demodulated digital data will be displayed on the oscilloscope, as shown in Figure 1-31.

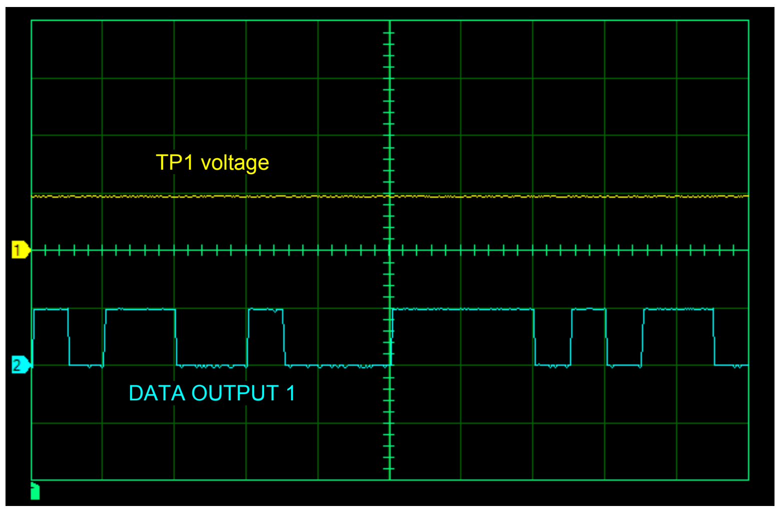


Figure 1-31. Costas loop locked.

Note the dc voltage at TP1; this is the locked-condition voltage.

Locked-condition voltage:___________ V

The locked-condition voltage is not necessarily the same on each Earth Station Receiver.

Locked-condition voltage: approximately 1.8 V

9. Turn the Center Frequency knob to either extreme position. Note that the dc voltage at TP1 does not change. When the Costas loop is locked, the feedback loop keeps this voltage at a virtually constant level and the Center Frequency control has no effect.

If this voltage at TP1 of the receiver is stable at the locked-condition voltage, you can assume that the Costas loop is locked.

10. Turn the Center Frequency knob to the center position (Position 3 in Figure 1-28).

Transmitting digital signals

16. Make the connections shown in Figure 1-32.

Note that the data is applied to DATA INPUT 5 of the Earth Station Transmitter. This DATA INPUT does not use the TDM MUX.

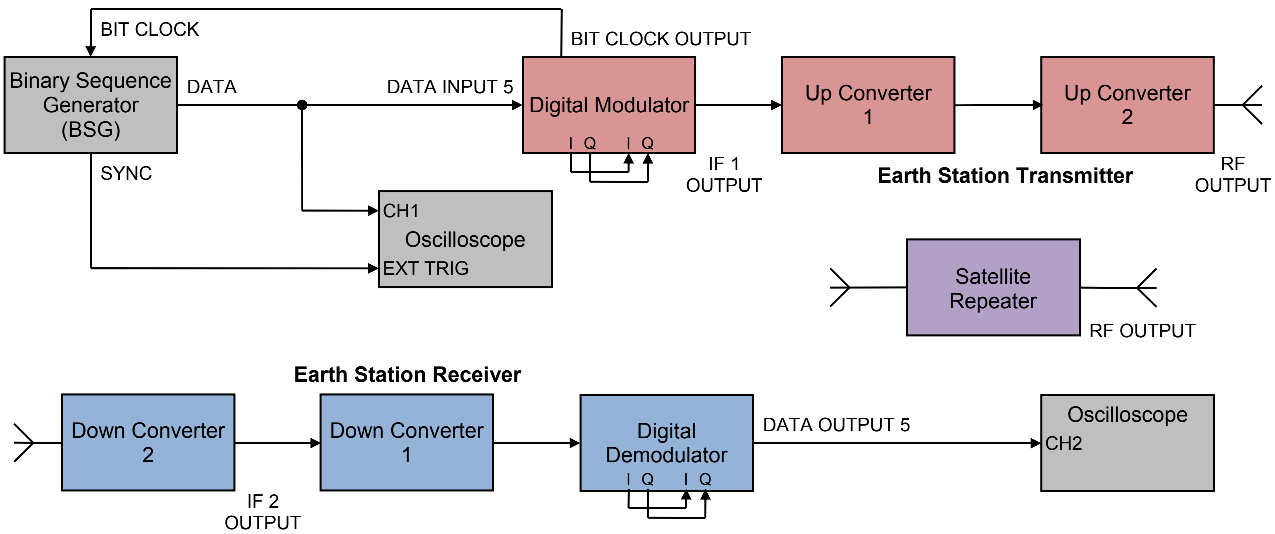
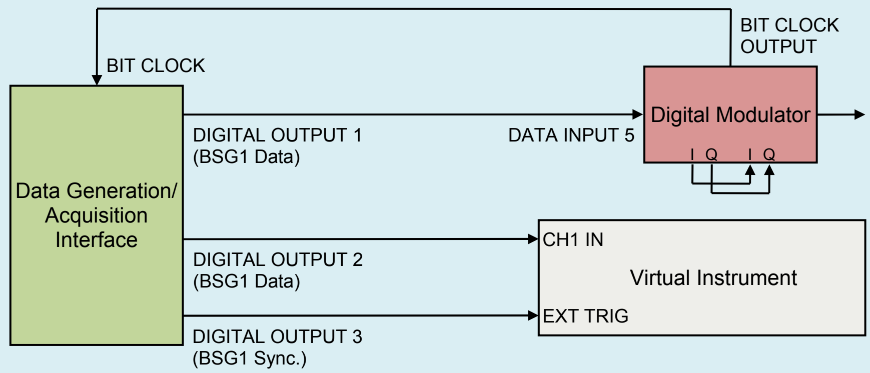


Figure 1-32. Connections for transmitting a digital signal.

Using the Telemetry and Instrumentation Add-On

You can configure the Data Generation/Acquisition Interface so that the data from one BSG is available at two different DIGITAL OUTPUTs, as shown below:



Make the following adjustments in the Telemetry and Instrumentation application:

Digital Output Settings:

⊡ Digital Output 1
Source BSG1
Signal .... Data

⊡ Digital Output 2
Source BSG1
Signal .... Data

⊡ Digital Output 3
Source BSG1
Signal .... SYNC.

Make sure the Clock & Frame Encoder on the transmitter is on and that the QPSK Costas Loop is still locked (the Frame Recovery Sync. LED should be lit).

On the Earth Station Transmitter, make the following adjustments:

Scrambler .... On
Clock & Frame Encoder .... Off

Turning off the Clock & Frame Encoder will cause the Sync. LED on the receiver to go off. The Costas loop, however, will stay locked.

On the Earth Station Receiver, make the following adjustments:

Descrambler .... On

Configure the binary sequence generator to generate a relatively short binary sequence, for example, a pseudo-binary sequence of length $L = 7$ or 15 bits ($n = 3$ or 4) or a user-defined sequence.

Figure 1-33 shows an example of what you might observe on the oscilloscope.

Oscilloscope Settings:
Channel 1 Scale ....5 V/div
Channel 2 Scale ....5 V/div
Time Base............................20 µs/div
Trigger Source ....EXT
Trigger Level.............................. 2.2 V
Trigger Slope .... Falling

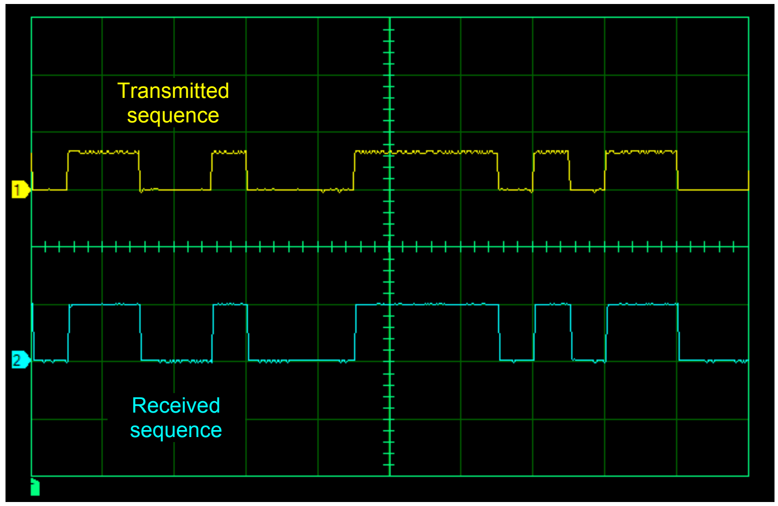


Figure 1-33. Transmitted and received binary sequence ($n = 4$, $R_b = 100\ 000$ bit/s).

Using the oscilloscope, compare the received binary sequence with the original binary sequence.

Vary the binary sequence and the bit rate.

The maximum bit rate at Data Inputs 1 to 4 on the Earth Station Transmitter is 4 Mbit/s. The maximum bit rate at Data Input 5 is 20 Mbit/s. (This is also the maximum Bit Rate for each BSG of the Telemetry and Instrumentation Add-On.)

You may need to adjust the Trigger Level a little as you vary the n value. It may be difficult to sync. the oscilloscope when using a very long sequence.

Refer to *Using the Telemetry and Instrumentation Add-On* for information on changing the binary sequence and the bit rate of the virtual BSG.

Is the sequence always recovered correctly at the receiver?

Yes, the two sequences are identical except for a slight delay in the received sequence.

What type of modulation is presently being used? Explain.

The modulation being used is DQPSK (quadrature phase shift keying with differential encoding), a type of digital modulation. Digital modulation is used because the baseband signal is a digital signal.

17. Exit the Telemetry and Instrumentation application.

Data transfer

In this section, you will transfer computer data from the Earth Station Transmitter to the Earth Station Receiver using the Data Transfer application, which consists of two separate programs: The Data Transmitter and the Data Receiver. Data is sent using the Data Transmitter via the Earth Station Transmitter. The data is received using the Data Receiver via the Earth Station Receiver. The Data Transmitter and Data Receiver can be run on the same computer or on two different computers.

18. Connect the modules of the Satellite Communications Training System as shown in Figure 1-34.

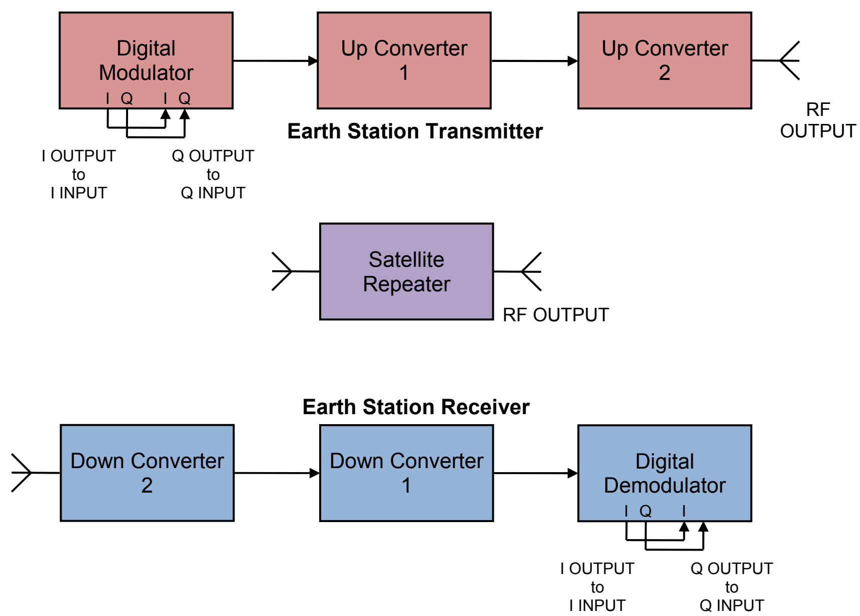


Figure 1-34. Module connections for data transfer.

On the Earth Station Transmitter, make the following adjustments:

Data Source .... TDM MUX
Scrambler .... On
Clock & Frame Encoder .... On

On the Earth Station Receiver, make the following adjustments:

Descrambler .... On

On the Earth Station Receiver, make sure the Costas loop is locked. The Sync. LED should be lit.

19. DATA INPUT 4 on the Earth Station Transmitter has a USB connector. DATA OUTPUT 4 on the Earth Station Receiver also has a USB connector. Connect these two USB connectors to one or two computers. There are a number of ways to make these connections, as shown in the examples below.

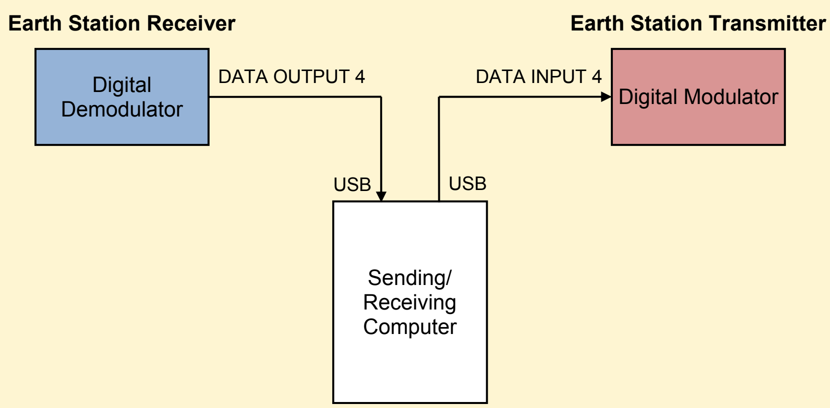
The use of two computers allows sending data from one computer (connected to the Earth Station Transmitter) over the satellite link to the other computer (connected to the Earth Station Receiver).

When using only one computer, this computer is connected to both the Earth Station Transmitter and the Earth Station Receiver. In this case, the data from the computer is sent over the satellite link and received by the same computer.

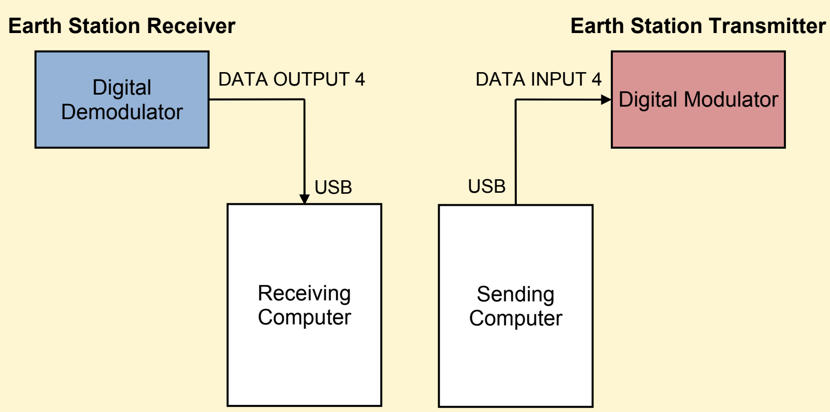
Note that only one computer can be connected to the Telemetry and Instrumentation Add-On.

USB connections for data transfer

Using one computer:

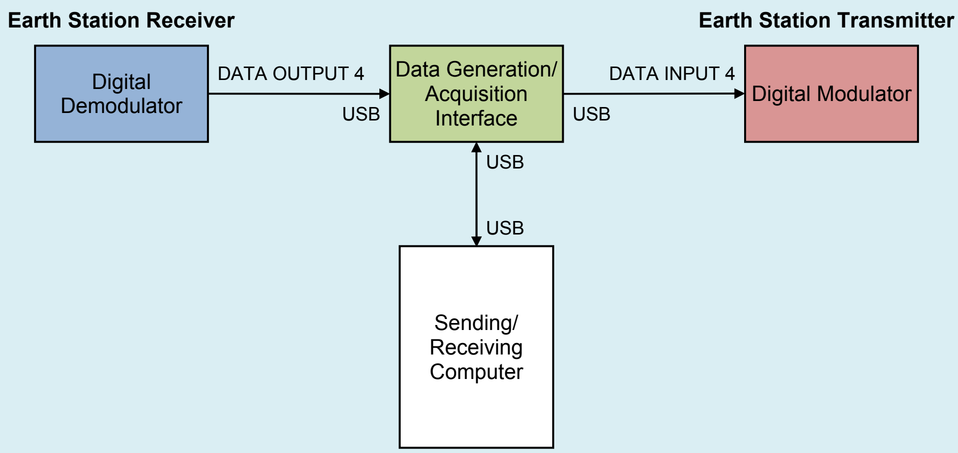


Using two computers:

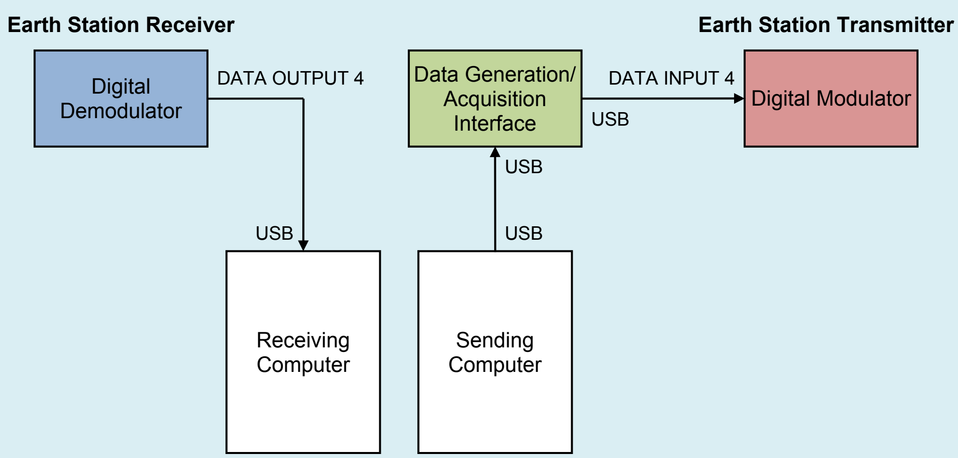


USB connections using the Telemetry and Instrumentation Add-On

Using one computer:



Using two computers:



20. Start the two Data Transfer applications: Data Transmitter and Data Receiver.

If you are using two computers, start the Data Transmitter application on the computer connected to the Earth Station Transmitter and the Data Receiver application on the computer connected to the Earth Station Receiver.

Make sure the green USB indicator in each of these applications is lit. This indicates that a connection has been established with the computer.

21. Select the Message tab in both the Data Transmitter and the Data Receiver.

In the Data Transmitter, type or paste a text message and click *Send*. The text message should appear in the Data Receiver.

22. Select the Real-Time Data tab in both the Data Transmitter and the Data Receiver. This tab simulates a remote weather station that continually sends meteorological data via a satellite link.

In the Data Transmitter, click the *Start* button. The current data is transmitted every second. Change any value and observe the received data in the Data Receiver.

Click the *Random Data* button to generate data that varies randomly every second. Note that the data is sent from the transmitter to the receiver every second.

23. Select the Files tab in both the Data Transmitter and the Data receiver. This tab allows sending files.

In the Data Transmitter, click the *Browse* button. Open a folder and select one or more files. The selected files will appear in the list (the previous list will be cleared).

The transfer rate via the USB port is approximately 2 Mbit/s. Transferring large files can take a considerable amount of time.

Since no error correction is provided by the data transfer applications, it is preferable to avoid transferring large files.

The Destination Folder in the Data Receiver shows where the received files will be placed. If you wish to change this folder, use the *Browse* button.

In the Data Transmitter, click *Send All*.

24. When you have finished using the system, exit any software being used and turn off the equipment.

CONCLUSION

In this exercise, you became familiar with the Satellite Communications Training System and learned how to optimize the antenna alignment. You observed the entire system in operation by transmitting and receiving analog and digital signals. You also observed data transfer over the satellite link.

REVIEW QUESTIONS

1. Name and briefly describe the two main subsystems of a communications satellite.

The two main subsystems are the payload and the platform. The payload consists of all the components that provide communications services, that is, which receive, process, amplify and retransmit information. The platform consists of all the components that maintain the satellite in the desired orbit and attitude and that permit the payload to operate and to remain operational over a long period of time.

2. Briefly describe the three segments of a satellite communications system.

   The space segment (SS) consists of all the satellite in space including backup satellites. It also includes the launch vehicles and all the facilities needed to place the satellites in the desired orbits. The ground segment (GS) consists of the traffic Earth stations and all ground-based facilities used for communications traffic. The control segment (CS) consists of all ground-based facilities required for the operation, control, monitoring, and management of the space segment.

3. Compare SCPC and MCPC and give some advantages and disadvantages of each.

   With SCPC (single channel per carrier), each carrier carries only one signal, that is, there is no multiplexing involved. With MCPC (multiple channels per carrier), a number of signals are multiplexed in the baseband before modulation in the transmitter and demultiplexed after demodulation in the receiver.

   SCPC is the simpler technique and allows flexible use of the available bandwidth without reconfiguration of the transponder. It makes it easy uplink from multiple earth stations to the same transponder and to add receiving earth stations. However, it uses the available bandwidth less efficiency than MCPC. MCPC is more efficient, does not require a dedicated channel for each connection, and is ideal for burst transmissions. However, it requires that all signals are multiplexed at one location and demultiplexed at another location.

4. The information carried over a satellite link is carried over different signals that occupy different frequency ranges. Briefly describe these signals and the purpose they serve.

   The baseband signal contains the information that one wants to transmit from one user terminal to another. It occupies frequencies between 0 Hz and the highest frequency in the signal. The baseband signal modulates a carrier at an intermediate frequency to produce an IF signal that occupies a frequency band considerably higher than the baseband. The IF signal is up converted in one or more stages to the RF frequency used to transmit the signal to the satellite. This RF signal occupies highest frequency band in the satellite communications system.

5. What are some of the main factors that influence the choice of RF frequency band used for different types of satellite links?

   The lower the frequency band, the better the propagation characteristics, but, the higher the frequency band, the greater the available bandwidth. With these higher frequency bands, antennas are more directional which allows using spatial separation to avoid interference between links using the same frequency.

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